ECONOMIC BOTANY

DEVOTED TO APPLIED BOTANY AND PLANT UTILIZATION

A Publication of
THE SOCIETY FOR ECONOMIC BOTANY

New Zealand Medicinal Plants — *S. G. Brooker and R. C. Cooper*

The Economic Botany of the Paulownias — *Shiu-Ying Hu*

Gamma Radiation Effects on Fruits and Vegetables — *D. K. Salunkhe*

The Cashew's Brighter Future — *Julia F. Morton*

Steroidal Sapogenins. LVIII. Steroidal Sapogenins from the Joshua Tree — *A. M. Woodbury, M. E. Wall, and J. J. Willaman*

Quadrangular Bamboo — *Robert E. Perdue, Jr., and John L. Creech*

The Freeze-drying of Pollens — *J. R. King*

A Note on the Biological Activity of Root Extracts from *Pleiocarpa mutica* Benth. (Apocynaceae) — *D. P. N. Tsao, J. A. Rosecrans, J. J. DeFeo and H. W. Youngken, Jr.*

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New Zealand Medicinal Plants

S. G. BROOKER and R. C. COOPER[1]

Despite the small area of New Zealand, comparable with that of California, it constitutes a distinctive botanic region. Of the approximate number of two thousand species of higher plants found, 75% are endemic to the country. Many unusual plants occur and the chemical investigations conducted to date have confirmed the unique nature of the flora.

In view of these facts it is surprising that only a few native plants have been commercially exploited. Several of the trees, notably *Agathis australis*, *Dacrydium cupressinum*, *Podocarpus totara*, *P. dacrydioides*, and *Vitex lucens* yield useful timber, but the stands of these have largely been worked out. New Zealand flax, *Phormium tenax*, is cultivated for its fibre which is made into ropes and matting. Kauri gum (really a fossil product) up to a value of £21 million has been exported but it is a declining article of commerce. It has been shown that useful dyestuffs can be produced from a number of plants, particularly in the genus *Coprosma*, but no commercial exploitation has resulted.

Pharmacology is probably the most promising field for extending the use of New Zealand native plants and it should therefore be of value to have a check list of those plants reported to have been used medicinally by the natives of New Zealand. This must necessarily include usage by early settlers as it cannot be decided with certainty what the settlers learned from the Maori and *vice versa*. Indeed some authorities on Maori culture believe that all medicinal use of plants by the natives was learned from the white man's example—a conclusion which seems contrary to the observations of Captain Cook and other early visitors to New Zealand. Other students of the Maori suggest that pre-European use of plants was external, e.g., in vapor baths and embrocations, and that the natives extended the use of these herbs after the *pakeha* (white man) arrived.

Historical Aspects

To see this question in its proper perspective, a few historical details are appropriate. Aside from a brief visit by the Dutchman, Abel Tasman, in 1642, European contact with the Maoris of New Zealand began with the visit of Captain James Cook in 1769. This visit was largely scientific in its purpose, and Cook was accompanied by two eminent botanists Sir Joseph Banks and Dr. Solander who laid the foundations of our knowledge of the New Zealand flora. Cook was a pioneer in recognizing the value of fresh fruit and greens as anti-scorbutics in the diet of his crew and he lost no opportunity to try out any suitable plants during his voyages of exploration. One of these was the New Zealand spinach (*Tetragonia expansa*). The Maoris may have learned from examples of this kind, but Cook certainly records the indigenous use of vapor baths in which various herbs were employed.

In the following years a number of navigators, explorers, whalers, and other sea captains visited New Zealand. Some lived among the Maoris and kept a few records while others made only a brief stay. In 1826 there were still only a handful of permanent white residents, mainly missionaries, but the Rev. William Williams recorded in his diary that Epsom Salts was a favorite remedy with the natives and that he had brought a

[1]Auckland Institute and Museum, Auckland, New Zealand.

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TABLE I

LIST OF MAORI MEDICINAL PLANTS

Plant	*Part Used*	*Reputed Use*
Algae		
Durvillea antarctica	Tender end	Scabies, worms, eczema
Porphyra columbina	Whole plant fermented	Aperient
Fungi		
Calvatea caelata	Reddish dust	Burns
Musci		
Lembophyllum clandestinum	Whole plant or leaves	Venereal disease, check menstrual bleeding.
Lichens		
?, (species unknown)	Dried powdered plant	Cutaneous eruptions.
Filices		
Asplenium bulbiferum	Root infusion	Skin troubles, sore eyes.
Asplenium obtusatum	Root	Skin troubles.
	Whole plant	Vapor baths.
Azolla rubra	?	Scalds of infants.
Blechnum fluviatile	?	Chewed for sore mouth and tongue.
Cardiomanes reniforme	Leaves	Ulcers.
Cyathea dealbata	Pith	Poultice for skin sores.
Cyathea medullaris	Pith	Swollen feet and sore eyes; dressing for sores and chafings.
	Young fronds	Inflamed mammae; Boils; to assist discharge of placenta.
	Slimy tissue	Wounds, poisoned hands.
	Gum	Vermifuge, diarrhea.
Cyclosorus pennigerus	Roots	Skin sores and ulcers, boils.
Marattia salicina	Rhizome	Diarrhea.
Pteridium esculentum	Root	Food for invalids; sea sickness; influenza.
	Burnt fronds	Severe burns.
	Fronds	Dysentery.
Coniferae		
Agathis australis	Gum	Burns.
Dacrydium cupressinum	Infusion of?	Ulcers.
	Gum	Stopping flow of blood internally and externally.
	Inner bark	Burns, wounds.
	Sap	Baldness.
	Leaves	Sores.
	Branches	Scurvy.
Phyllocladus trichomanoides	Bark	Dysentery.
	Leaves	Scrofula.
Podocarpus dacrydioides	Leaves	Vapor baths; urinary and other internal complaints.
	Bark	Bruises, tonic.
Podocarpus ferrugineus	Oil	Tonic after fever.
	Gum	Wounds and ulcers.
	Leaves & bark	Gonorrhea.
	Bark	Stomach ache; antiseptic.
Podocarpus spicatus	Sap	Consumption.
Podocarpus totara	Smoke from burning wood	Skin disease, venereal disease, piles.
	Bark	Splints in bone fracture.
	Inner bark	Fever.
Angiospermae		
AGAVACEAE		
Cordyline australis	Leaves	Dysentery, diarrhea, cuts.
	Scrapings of leaves	Cuts, skin cracks, sores.
	Young shoots	Colic, tonic for nursing mothers.
Phormium colensoi	?	Skin diseases.
Phormium tenax	Gum	Burns, wounds, old sores; diarrhea.
	Root sap	Constipation; gunshot and bayonet wounds.

	Decoction of the root	Flatulence, wounds and amputations, chilblains, tonic, stoppage of menses, constipation, stomach upsets, worms, foul breath.
	Root	Colds, headaches, abscesses, swollen joints, worms, wounds, general tonic, ringworm, skin chafing.
	Butts of leaves	Burns, wounds, lacerations, constipation, rheumatism, sciatica, gonorrhea, tumors, abscesses.
	Fibre	Wounds (as a dressing).
	Leaves (strongest parts)	(Splints for) broken limbs.
ARACEAE		
Zantedeschia aethiopica	Rhizome	Abscesses, boils.
ARALIACEAE		
Meryta sinclairii	?	Used to produce abortion.
Schefflera digitata	Sap	Scrofula, ringworm.
CHENOPODIACEAE		
Chenopodium album	Leaves (infusion)	Boils, blood trouble.
COMPOSITAE		
Brachyglottis repanda	Leaves	Wounds, ulcers, boils.
	Gum	Foul breath.
Celmisia sp.	Leaves	Asthma.
Gnaphalium keriense	Leaf sap	Bruises.
Lagenophora petiolata	Sap	Ulcerated mouth, general complaints.
Onophordon acanthium	Sap	Cuts and sores.
Sonchus oleraceus	Sap and leaves	Cutaneous eruptions, stomach complaints, carbuncles. Hemorrhage after childbirth. Also used as blood purifier, antiscorbutic, and slight laxative, and on cuts to prevent poisoning.
Taraxacum magellanicum	Roots	Alterative.
CONVOLVULACEAE		
Calystegia sepium	Root	Poor flow of milk in women.
Ipomoea batatas	Whole plant or infusion	Low fever, skin diseases.
CORIARIACEAE		
Coriaria arborea	Shoots	Boils, bleeding cuts, dysentery, sprains, bruises.
	Extract of leaves	Sores, cuts and inflammation, dysentery, wounds, broken legs, bruises.
	Pith (Plaster)	Wounds, insanity, broken bones.
	Sap (Plaster)	Broken bones.
	Fruit	Constipation.
	Bark	Broken bones.
	Root	Neuralgia, rheumatism, eyestrain
CORNACEAE		
Corokia buddleoides	Extract of leaves	Stomach ache.
Griselinia littoralis	?	Constipation.
	Inner bark	Scrofula, venereal disease.
CORYNOCARPACEAE		
Corynocarpus laevigata	Leaves	Wounds.
CRUCIFERAE		
Brassica oleracea	?	Colic.
Brassica rapa	Juice	Hemorrhage after childbirth
Lepidium oleraceum	Leaves	Scurvy.
Nasturtium officinale	Whole plant	Headaches (applied as a pack).
CUNONIACEAE		
Weinmannia racemosa	Bark	Stomach pains, constipation, tonic
Weinmannia sylvicola	Bark	Burns, cuts.
CYPERACEAE		
Mariscus ustulatus	Pith	Kidney trouble.
Scirpus lacustris	Leaf sap	Blindness.

ELAEOCARPACEAE		
Aristotelia serrata	Leaves	Burns
	Extract of leaves	Burns, rheumatism, boils, sore eyes.
	Infusion of bark	Sore eyes, rheumatism.
Elaeocarpus dentatus	Decoction of bark	Skin disease.
EPACRIDACEAE		
Cyathodes acerosa	Leaves (infusion).	Kidney trouble, asthma, menstrual disorders, septic wounds.
Leucopogon fasciculatus	Leaves (infusion).	Headaches and influenza.
ERICACEAE		
Gaultheria antipoda	Leaves	Wounds, cuts.
	Infusion of leaves	Wounds, cuts, asthma.
EUPHORBIACEAE		
Euphorbia glauca	Whole plant (infusion)	Skin troubles.
Euphorbia peplus	Whole plant (infusion)	Skin troubles.
FICOIDACEAE		
Disphyma australe (also known as *Mesembryanthemum australe*)	Sap	Boils.
Tetragonia expansa	Leaves	Scurvy.
GERANIACEAE		
Geranium dissectum	Leaves	Boils, sore backs.
Geranium microphyllum	?	Aches and pains.
Geranium molle	Infusion	Chest pains in tuberculosis, sepsis wounds, contusions.
Pelargonium inodorum	Leaves (infusion)	Burns, pimples, scalds, bruises.
	Leaves	Foul breath.
GESNERIACEAE		
Rhabdothamnus solandri	Leaves & twigs	Vapor baths.
GRAMINEAE		
Arundo kakaho	Ash	Burns.
	Fronds	Bleeding.
	Leaves	Diarrhea.
	Stem	Kidney trouble.
	Juice	Dirty tongue in infants.
Hierochloe redolens	?	Vapor baths.
Poa caespitosa	Whole plant	Rheumatic pains, burns.
HALORAGIDACEAE		
Haloragis erecta	Sap or infusion	Scrofula.
HYPERICACEAE		
Hypericum perforatum	?	Headaches, measles, influenza.
LABIATAE		
Mentha cunninghamii	?	Used as a diaphoretic.
LAURACEAE		
Beilschmiedia tawa	?	Wounds, stomach pains, colds.
Litsea calicaris	?	Used in vapor baths and midwifery.
LEGUMINOSAE		
Sophora tetraptera	Bark	Pains internally or in back or side Constipation, itch, scrofula, tumors broken limbs, bruises.
	Sap	Gonorrhea.
	Ashes	Ringworm.
	Infusion	Colds and sore throats.
Sophora microphylla	Bark infusion	Pains internally or in back or side, skin disease, bruises and fractures.
LILIACEAE		
Arthropodium cirrhatum	Base of leaves	Ulcers.
	Roots	Unbroken tumors and abscesses.
LOGANIACEAE		
Geniostoma ligustrifolium	Sap	Skin disease in children.
	Bark	Itch.
MAGNOLIACEAE (WINTERACEAE)		
Pseudowintera axillaris	Bark	Fever.

	Sap	Skin disease, gonorrhea.
	Leaves (infusion)	Stomach ache, skin disease.
	Leaves (chewed)	Toothache.
	Leaves (rubbed on breasts)	Wean infants.
MALVACEAE		
Hoheria populnea	Bark (infusion)	Colds, weak and sore eyes, burns.
Dysoxylum spectabile	Leaves and bark	Tonic, stomach troubles, coughing, to stop flow of milk.
	Red pulp	Consumption.
	Infusion of leaves	Lung hemorrhage, colds, fever tonic, "woman's disorders," sore throats, boils, gonorrhea.
	Whole plant (?)	Convulsions.
MONIMIACEAE		
Hedycarya arborea	Leaves	Vapor baths.
Laurelia novae-zealandiae	Bark (infusion)	Tuberculosic and chronic ulcers, skin complaints, toothache, syphilis, neuralgia.
MYOPORACEAE		
Myoporum laetum	Bark	Ulcers, eruptions, toothache.
	Twigs & leaves	Steam bath.
	Leaves	Bruises, septic wounds, baby eczema.
MYRSINACEAE		
Myrsine australis	Leaves (infusion)	Toothache.
MYRTACEAE		
Eucalyptus globulus	Leaves (infusion)	Post-partum bath and to cure post-partum hemorrhage, asthma.
Eugenia maire	Bark	Ringworm.
Leptospermum cricoides and *L. scoparium*	Capsules (infusion)	Diarrhea, colic, fever, inflammation of breast.
	Capsules (poultice)	Open wounds, running sores.
	Gum	Scalds, burns, coughing, given to suckling infants to cure constipation.
	Bark (infusion)	Sedative, dysentery, diarrhea, skin disease, internal and external pains, fever, mouth, throat, eye trouble, inflamed breasts.
	Sap	Blood and breath purifiers.
	Leaves (infusion)	Colds, pains internal and external, dysentery, vapor baths, urinary and internal complaints.
Metrosideros albiflora	Bark (infusion)	Pains, bleeding, wounds.
	Sap	Women's complaints.
Metrosideros excelsa	Bark (infusion)	Diarrhea.
	Nectar from flowers	Sore throat.
Metrosideros robusta	Nectar	Sore throat.
	Bark (infusion)	Sores, bleeding, ringworm, colds, bruises, aches, pains and wounds, venereal disease.
	Sap	Stops bleeding of wounds, tonic.
	Leaves	Toothache.
Metrosideros scandens	Sap	Eye troubles, wounds, tonic, coughs, antiseptic.
	Bark	Sores, bleeding.
Myrtus bullata	Leaves	Bruises.
Myrtus obcordata	Bark & berries (infusion)	Dysmenorrhea.
ONAGRACEAE		
Fuchsia excorticata	Whole plant	Vapor bath and internal hemorrhage after childbirth.
PALMAE		
Rhopalostylis sapida	Pith and sap	Relax muscles in childbirth, laxative.
PASSIFLORACEAE		
Tetrapathaca tetrandra	Seed oil	Chronic sores, chapped nipples.

PIPERACEAE		
Micropiper excelsum	Leaves & bark	Cuts, wounds, stomach pains, gonorrhea, steam baths.
	Leaves	Boils, toothache, stomach pains, skin disease, kidney trouble, eczema, V.D., bruises, rheumatism, wounds, worms, blood impurity, bladder complaints.
	Root	Toothache, urinary complaints.
	Fruit and seeds	Excite the salivary glands, kidneys and bowels. Slightly diuretic and aphrodisiac.
PITTOSPORACEAE		
Pittosporum eugenioides	Gum	Foul breath.
Pittosporum tenuifolium	?	Itch, eczema of scalp and skin diseases.
	Leaves	Ague.
PLANTAGINACEAE		
Plantago sp.	Leaves (poultice)	Ulcers.
	Leaves (infusion)	Scalds, burns, uterine disorders, retention of the placenta, cuts, boils.
	Sap	Cracked lips, boils, burns, cuts, pains generally, septic wounds.
	Whole plant (?)	Piles.
POLYGONACEAE		
Polygonum serrulatum	Whole plant (infusion)	Rheumatic pains.
Rumex sp.	Similar uses to *Plantago* sp.	
PROTEACEAE		
Knightea excelsa	Bark	Used on wounds to heal and stop bleeding.
RANUNCULACEAE		
Clematis hexasepala	Bark and stems (infusion)	Mild alterative.
Clematis paniculata	Leaves	Used to produce blisters as a counter irritant.
	Sap	Wounds.
	Bark and wood	Colds in the head.
Ranunculus hirtus	Whole plant	Toothache, inflamed eyes, abrasions.
Ranunculus rivularis	Sap	Rheumatism and joint diseases.
	Infusion of leaves	Quinsy.
RHAMNACEAE		
Pomaderris elliptica	Leaves (infusion)	All chest complaints, bronchitis and consumption, heartburn, kidney complaints, skin cancer, diabetes, coughs, sores, colds, constipation, asthma. Said to be blood and skin purifier.
ROSACEAE		
Acaena sanguisorbae	Leaves (infusion)	Wounds and contusions, painful micturition, rheumatism, kidney and bladder trouble, stomach troubles and as a general tonic.
Geum urbanum	Leaf	Diarrhea, dysentery, foul breath.
Rubus cissoides	Bark (infusion)	Purgative in cases of severe abdominal pain. Vapor baths to assist in childbirth.
	Decoction (of?)	Dysmenorrhea.
	Leaves (infusion)	Congestion in the chest, hard cough, sore throat, constipation.
RUBIACEAE		
Coprosma australis *Coprosma acerosa* *Coprosma robusta*	Sap	Skin diseases.
	Leaves (infusion)	Broken limbs, bruises, fever, cuts, festered sores, kidney trouble.
	Leaves (poultice)	Broken limbs.
	Bark (infusion)	Broken limbs, bruises, scabies, itch, cuts, stomach ache, vomiting, aches and pains, venereal disease.
	Young shoots	Bladder stoppage and inflammation.

Galium umbrosum	Whole plant	Gonorrhea—particularly with retention of urine.
RUTACEAE		
Melicope ternata	Gum	Foul breath.
SAPINDACEAE		
Alectryon excelsum	Oil	Weak eyes, sore wounds, sore breasts, chapped skins, bruises, painful joints, earache, constipation, sore or hard navel in the newborn.
	Red pulp	Hemorrhage in consumption.
SCROPHULARIACEAE		
Hebe salicifolia	Whole plant	Vapor baths.
(*Veronica salicifolia*)	Leaves (infusion)	Dysentery (very effective), infantile diarrhea, kidney and bladder troubles, skin troubles, headaches, laxative, to promote easy delivery in childbirth, also as mouthwash and gargle.
	Leaves (poultice)	Ulcers, venereal disease.
	Sap	Skin disease.
SMILACEAE		
Rhipogonum scandens	Stem (burnt)	Cauterizing wounds.
	Stem (poultice)	Venereal disease.
	Sap	Wounds, also demulcent.
	Root (infusion)	Rheumatism, bowel complaints, fever, general debility, skin disease, secondary symptoms of syphilis. Also used to produce abortion and as a substitute for sarsaparilla.
	Young shoots	Itch.
SOLANACEAE		
Solanum aviculare and *S. laciniatum*	Whole plant	Poultice for sores, ulcers.
	Sap	Itch, scabies, wounds, produced by tattooing instruments.
	Pith of stem	Bruises.
	Bark	Scabies, ulcers, itch.
	Leaves	Wounds, cuts.
Solanum tuberosum	Water in which tuber is boiled.	Pimples, ague, skin eruptions, burns.
TYPHACEAE		
Typha angustifolia	Pappus of seeds	Wounds, ulcerated sores.
	Rhizome (infusion)	Assist removal of the afterbirth.
UMBELLIFERAE		
Angelica rosaefolia	Leaves	Used as diuretic and in syphilis.
Apium prostratum	Whole plant	Vapor baths, antiscorbutic.
URTICACEAE		
Urtica ferox	Bark (infusion)	Eczema and venereal disease.
VERBENACEAE		
Vitex lucens	Leaves (infusion)	Sprains and backache, ulcers (especially under the ear), sore throats.
VIOLACEAE	Leaves (infusion)	Rheumatism, scabies.
Melicytus ramiflorus	Bark	Burns.

supply from England which sold at £1 a hundredweight. Later students of the Maori report that "He developed a marvellous appetite for medicine no matter what the remedy might be, or whether he possessed any ailment or not."

The situation is further confused by the difficulties of the Maori language in which one word has several meanings and by a lack of interest in the subject by the early traders and missionaries. The Maori certainly used plants in various mystical rites associated with sickness and death, and it is hard to decide where

magic ended and medicine began. Because of all these factors it might be emphasized that the inclusion of plants in the list below does not mean they were necessarily effective in medicine. Few genuine cures can be substantiated and some of the concoctions contained known poisons. Nevertheless the list may give some clues to the use of these plants or their products in modern pharmacy. To round off this paper we have included a list of compounds found in New Zealand plants of actual or potential value in pharmacy.

In the final part of this paper we propose to review briefly those plants and chemical substances found in them which appear to be of potential value in chemotherapy. We are indebted to a very useful review of New Zealand plant chemistry of Briggs (2) where many observations are made which come within our survey. It may also be mentioned that the research program of the New Zealand branch of the British Empire Cancer Campaign includes an investigation of the local flora for substances of significance in cancer therapy. This work is still in progress.

Fungi

New Zealand species of ergot contain ergotamine and ergotaminine (13).

Lichenes

The common lichen *Sticta coronata* has shown promise in the treatment of leukemic mice (Burton and Cain, Nature, in the press 1959).

Filices

Methyl salicylate (oil of wintergreen) has been found in *Asplenium lamprophyllum* but not in other species of this genus (5).

Coniferae

The fossil gum of the Kauri pine, *Agathis australis* contains as a major constituent agathic acid which has a similar carbon skeleton to Vitamins A, E and K (2).

Podocarpus dacrydioides and *Dacrydium cupressinum* both contain podocarpic acid which is estrogenic (1). The propionate of podocarpic acid is effective in promoting the flow of bile (12). *Podocarpus spicatus* contains genistein, an estrogenic isoflavone (4), and mataireSinol found to have antimitotic properties and tumor necrotising action in mice (17).

Angiospermae

AGAVACEAE

So many reports have been received about the healing properties of the gum found at the base of the leaves of *Phormium tenax*. (New Zealand flax) that it is difficult to believe there is no virtue in it, but McIlroy (16) found nothing significant in the analysis.

CORIARIACEAE

Coriaria arborea, called tutu by the Maoris and "toot" by the white man, contains tutin, a violent poison, in its leaves and seeds (10). Tutin is similar in its action to picrotoxin.

CORYNOCARPACEAE

The berries of karaka (*Corynocarpus laevigata*) contain a poisonous principle karakin shown by Carter (9) to be 1, 4, 6 *Tris*-(3-nitropropionyl)-D glucopyranose. At the time it was the only compound with a nitro group found in nature.

FICOIDACEAE

Tetragonia expansa, New Zealand spinach, has already been referred to. It shows carbonic anhydrase activity (6) and therefore has the opposite effect to the sulphomanide drugs.

LAURACEAE

β sitosterol has been found in the bark of *Beilschmiedia tawa* (W. E. Harvey, unpublished work).

LEGUMINOSAE

A very extensive survey of the alkaloids of the Leguminosae in New Zealand has been reported by White (20). Hold-

gate (14) has isolated anagyrine and diosmin from *Sophora microphylla*.

MALVACEAE

Hoheria populnea has been suggested as a substitute for slippery elm bark.

MELIACEAE

Dysoxylum spectabile contains β sitosterol and much tannin both in bark and heartwood which also contains catechin (7, 8).

MONIMIACEAE

The bark of *Laurelia novae-zealandiae* contains the alkaloid pukateine which is reported to be similar to morphine in its action but without its side effects (11).

MYOPORACEAE

Myoporum laetum, the ngaio, contains ngaione, a derivative of furfural, which suggests that it could be fungicidal. Ngaio has been found to be toxic and to cause liver damage in sheep. (Dacre, private communication).

MYRTACEAE

Leptospermum species contain leptospermone which has anthelmintic properties, and is a synergistic insecticide (2).

PIPERACEAE

The use of *Macropiper excelsum* as a painkiller by the natives could be due to the presence in its essential oil of myristicin a substance which is very similar chemically to eugenol the major constituent of oil of cloves.

RHAMNACEAE

The leaves of *Pomaderris elliptica* have been a widely advertised herbal tonic for many years and an ointment made from it is currently being sold by local herbalists for skin cancer.

RUTACEAE

Phebalium nudum bark contains β sitosterol (3).

RUBIACEAE

The barks of *Coprosma* species are rich in anthraquinone pigments which are interesting because they are substituted in the 2-position also found in a number of important mould metabolites discovered by Raistrick (18). Anthraquinone derivatives are also of possible significance as purgatives.

SCROPHULARIACEAE

The koromiko (*Hebe salicifolia*) is the only plant to have received any recognition in medicine overseas and was included in some editions of the Extra Pharmcopoeia. It is still esteemed as a remedy for diarrhea and during World War II quantities of the dried plant were sent to the North African front where it was effectively used by the Maori troops.

SOLANACEAE

The alkaloids of the native species of *Solanum* species have been extensively studied by Briggs and his school. Solasodine, solmargine, and solasonine and more particularly their hydrogenated derivatives have considerable antiaccelerator cardiac activity (15). Solasodine is of great interest because it is the nitrogen analogue of diosgenin and could be the starting point for the synthesis of a series of nitrogen-containing steroids.

VERBENACEAE

The bark of the puriri *Vitex lucens* contains vitexin which is also found in *Vitex peduncularis* reported to be of great value in the treatment of various fevers and for antihaemolytic activity against cobra venom (19). Vitexin has been shown to have no antibiotic activity. The heartwood contains β sitosterol, while β-carotene and *p*-hydroxybenzoic acid are found in the leaves. *p*-hydroxybenzoic acid derivatives are well known germicides and preservatives.

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Utilization Abstract

Medicinal Plants of the Arid Zones. This is one of a series of research papers on arid lands sponsored by UNESCO. Contained in the paper are botanical and pharmacological surveys of the plants of arid lands in all arid areas of the world. An ecological discussion of the lands, and adaptation to the arid environment open Part I. A listing of the chemical constituents of medicinal importance from various families of plants is provided, followed by a description of the individual species and its geographical distribution.

Large numbers of arid zone plants contain alkaloids. Members of the family Solonaceae are the richest alkaloid producers, especially *Datura, Hyoscyammus,* and *Solanum* spp. Alkaloids are also abundant in some members of the Papaveraceae, and the Curcurbitaceae. Various arid zone plants are also rich in essential oils, gums, sapogenins, etc.

Part II is introduced by general considerations of pharmacology and a discussion of the influence of aridity on content of active principles. Following these paragraphs, a description of various plants, listed by the type of active principles is given, for example: "Liliaceae yielding cardiotonic heterosides; Liliaceae yielding anthracenic heterosides," etc.

An extensive bibliography and a list of arid zone medicinal species are appended.

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The Economic Botany of the Paulownias

The wood of paulownia is strong and light. It is extensively employed in eastern Asia for building, furniture, musical instruments, chests, clogs and plywood. The potentiality of using paulownia wood in the aeronautical age for the manufacture of crating and boxing lumber for airplane express or freight shipment is highly appraised. The possibilities of employing paulownia wood in small boat building and for carving and the use of paulownia chips as bedding in dairy barns or as litter in chicken houses are excellent. The Chinese practice of administering parts of paulownias for the growth of hair and in other fields of medicine are reviewed. These practices await scientific investigation and evaluation.

SHIU-YING HU[1]

INTRODUCTION

On one bright morning in May, as I passed a small church in Kingston, New Jersey, I suddenly caught the unexpected sight of a fully blooming paulownia in the back yard of the village church and was astounded by the sheer beauty of the tree. The large globose mass of soft color of light-lavender in the air against the blue sky behind a quiet country church was a matchless scene of transient glory.

The paulownias have been introduced to America for ornamental purposes. The first trees were probably introduced from Europe about 1844. They rapidly rose to a wide popularity. Words of praise of the rare beauty of the flowering tree can be found in the magazines of horticulture and botany of that period. At first the enthusiasts of exotics eagerly paid three to six guineas for an individual plant. By 1847 the American nurserymen learned the secret of propagating the species by root cuttings. As Downing (*2*) wrote in that year that any little piece of the root can produce a plant. This method of propagation caused a steep drop in the price of young plants and one could pay thirty to sixty cents for an individual. In a period of twenty years the paulownias became widespread in gardens in eastern North America. It could be found from Montreal in Canada to Louisiana. However, the dull mess of persistent fruits which over-winter on the tree was unappealing to some American growers and the paulownias have never become as prominent in American landscapes as the day lilies, or the forsythias and spiraeas in the north and the pyracanthas and crape myrtles in the south.

In the Far East the story is very different. There the paulownias have attained widespread popularity and have maintained it throughout the ages. In China and Japan people have, as in Europe and America, been attracted by the fully blooming trees and use them extensively as a roadside tree. Moreover, they have advanced one step beyond the aesthetic aspect in their relation with the species and have discovered the special characteristics of the wood and used it in the construction of houses, in the manufacture of household articles, musical instruments and temple wares, and in medicine. In other words, the paulownias have not only entered the landscape in the Orient, they have also been woven into the fabric of the complicated pattern of the cultural and economic life of the people.

PAULOWNIAS IN THE LIFE OF THE PEOPLE IN CHINA AND JAPAN

Our knowledge of the role of the paulownias in the life of the people in eastern Asia, the native home of the species, is drawn from present day observations and ancient records. The evidences are con-

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vincing that the paulownias have entered into the cultural, economic and religious life of the Chinese people for many thousands of years. The earliest record on this subject is found in a book called *Erh-ya*, the first Chinese encyclopedia on natural and cultural objects. The authorship and date of publication of this work are subjects of dispute among historians. Traditionally the authorship of *Erh-ya* is attributed to Chou Kung, the Duke of Chou and son of the first ruler of the Chou Dynasty (B.C. 1122-255). Many historians believe that *Erh-ya* was prepared in the late Chou period. Although the authorship and date of publication of *Erh-ya* cannot be ascertained, there is one thing about the book of which we can be certain. *Erh-ya* represents the only existing Chinese record in which the ancient people transformed the prehistorical word of mouth knowledge of the natural history in their environment into a written form of historical record. On this Chinese milestone which marks off the prehistorical and the historical eras in the Orient we can read the effects of paulownias in the life of that ancient people. In article fourteen the term *Yung-tung-mu* (Glorious Paulownia Wood) appears among a list of useful woody plants. This name indicates that long before the Christian era the paulownias had entered the aesthetic and the economic life of the Chinese people who had described the flowering tree as "glorious" and found the "wood" useful.

Cultural Aspects

Paulownia in the legend of the Chinese populace. A conventional legend among the Chinese people portrays paulownia as the only tree species on which the phoenix perches. It is further believed that the phoenix never appears before the people unless there is a benevolent ruler to take command over the land. The phoenix is said to be an auspicious bird which lights only on the best kind of trees and the paulownia meets the requirements. In this connection and as a sign of good omen, the paulownias are extensively planted.

Paulownia in the belief of the Chinese intelligentsia. With the exception of the last fifty years in the history of China the Chinese intelligentsia were under the influence of the teachings of Confucius. In this school of thought the highest attainmen of an educated person is to become a *chun-tzu*, a man of complete virtue. Meanwhile, the educated Chinese had a profound knowledge of the nature of the paulownias. They knew that when a paulownia tree is alive the wood is soft and brittle and it resists no axes. However, after the tree is dead its timber becomes firm and strong. It does not crack in drying nor decay in soaking. For the tenderness of heart and stability of character, paulownia is taken as an emblem of *chun-tzu*. Consequently, a garden with paulownias is always regarded as a gathering place for the Chinese intelligentsia who may drink their mutual health and compose poems for each other.

Paulownia in religious practices. The natural habitat of the paulownias is the open marginal area of the mesophytic forest of the temperate zone. In China the forests in the flood plains, alluvial fans and gentle slopes of this zone have long been exterminated because of the ever increasing demand of land for agriculture. These forests were destroyed through burning, a technique practiced since time immemorial by all the tribes living in China and is still operating extensively in the mountainous area throughout the country, especially in southern and western China. As a consequence of the ruthless burning of the forests in arable areas a spontaneous growth of paulownia can never be found except on the steep slopes of the out-of-reach mountainous areas. Since the dawn of the historical era in China the Taoist monks have retreated to the scenic spots of the less inhabitable

areas. Later, Buddhism was introduced into China and became popularized in the Tang Dynasty. Some Buddhist temples were also established in such localities. The monks, especially the Taoists, live very close to the land and they have intimate knowledge of the natural history of their regions.

From the observations with the cultivated paulownias we know that when proper pruning is not given to a young tree, the small dead branches may introduce a growth of decaying fungus into the pith of the trunk of the living tree and produce heart rot. As the tree grows in girth, the rot increases in size. When such a tree is felled and the wood dried in the air, the rot stops spontaneously. This condition sometimes happens in nature. In western China where spontaneous paulownias may be found occasionally in the mountains, a hollow paulownia trunk was once discovered by a monk who had a natural gift of art and imagination. He roughly carved the trunk into the shape of a fish and had it hung inside the temple yard. It is the custom for all monks to get up for the morning prayers when the cocks crow. Eventually this first wooden fish had become the morning bell in the temple, for a deep thunder-like sound can be produced when the fish is beaten by a strong stick. In the Chinese language the sound for the characters standing for "fish" and "abundance" are homonyms. It is a Chinese custom to use a fish figure in art objects to express good wishes for an abundant life with boundless blessings. Incidentally, the pattern of having a wooden paulownia fish hung inside the temple gate has been copied among the religious institutions and the beating of the wooden fish for daily prayers has become a time-honored custom in Chinese temples.

Paulownia in the culture of the Japanese people. When Siebold and Zuccarini proposed the generic name *Paulownia* in 1835 (8) they commented: "We have taken the liberty of naming this new genus *Paulownia* for the form Kiri which has been taken as a *Bignonia* to render homage to her Imperial and Royal Highness, the hereditary Princess of the Netherlands. . . . It is not only for the beauty of the plant but also for the reason that the leaves with three branches of flowers have served as the coat of arms of the celebrated hero, Taikasama, that the Kiri is very much honored in Japan."

A more recent incident illustrates that paulownia has as prominent place in Japanese culture today as it had two hundred years ago. On June 21, 1960, the Japanese Consul General of New York City, Mitsuo Tanaka, presented an ensignia of the grand cordon of the order of rising sun with paulownia flowers to General Douglas MacArthur to honor him. This represents the highest decoration Japan can confer on a foreigner who is not a head of state, and paulownia is symbolically employed.

Economic Aspects

Paulownia for domestic constructions. Ch'en Chu (1) in 1049 A.D. published a repertory of the paulownias (Tung-p'u). Regarding the utilization of the species he commented that alternate drying and soaking have no ill effect on the wood of paulownia. Hence it is the best material for beams, ridge-poles and pillars in the construction of houses and it is superb for coffins. However, the natural stand of paulownia is rare and the lumber never reaches the rich people in cities. It is only occasionally employed by people in the mountains.

Paulownia for small industries. The people in China have learned through experience that the paulownia wood is light and strong. It is extensively employed in the chest making industry throughout the country. In South China where people prefer clogs to shoes, paulownia wood is used in making this kind of foot-wear. The wood of the white flowered species is

especially preferred in the making of musical instruments.

In the Buddhist monasteries the monks prefer to use wooden rice pots, bowls and spoons in their meals. Many of these woodwares are carved from paulownia wood.

Stearns (9) in 1944 published an article on Paulownia as a tree of commerce. He estimated that the annual consumption of paulownia wood in Japan exceeds 100,000,000 board feet. The important products from paulownia wood are wooden clogs, "tansu" (a combination of trunk and chest of drawers), musical instruments, lacquered boxes, furniture, portable temple models and card-board boxes.

In northern Japan, particularly in the town called Yamagata, paulownia wood is used for the manufacture of veneer for surfacing decorative boxes and fancy containers.

Paulownia for health and beauty. A majority of the Chinese people depend upon the traditional Chinese style medicin whereby the doctors prescribe plant or animal material and minerals for the cure of diseases, the restoration of health and for the promotion and maintenance of beauty. In the past ten years this old fashioned medicine has received cheerful encouragement from the government on the mainland of China. In the Chinese style medicinal practices the bark, wood, leaves, flowers and fruits of paulownia are employed.

An aqueous solution prepared from the leaves and capsules of paulownia is prescribed for daily application over the head for the promotion of healthy growth of hair and another for turning gray hair black. An aqueous solution prepared from the leaves and wood of paulownia is prescribed to patients having swollen feet. A tincture prepared from heating the inner bark of paulownia in two parts of water and one part of whisky is administered internally to patients having high fever and delirium. The leaves steamed in vinegar or the ground bark fried in vinegar are prescribed as dressings for bruises. An aqueous concoction made from the flowers of paulownia, the seeds of Sour Chinese Dates (Suan Tsao Jén) and the ground root of an umbelliferous plant (Ch'iang Huo) is administered internally for the cure of ailments of the liver or bile which cause dizziness.

In an age when effective antibiotics and wonderful pills are extracted increasingly from flowering plants as well as molds, scientific investigations into the active principles in the bark, wood, leaf, flower and fruit of different species of paulownias and qualitative evaluations of the empirical remedies derived from paulownia for the promotion of hair growth and for the cure of swollen ankles or dizziness which are usually symptoms of ailments of important internal organs such as the heart or the liver, may eventually lead into important discoveries which will bring profit to some people and the well-being of many others.

PROPERTIES OF THE WOOD

Anatomical and physical properties. Our knowledge of the anatomical characters and the physical properties of *Paulownia* is not complete because the wood of several known species has not been studied by wood anatomists. However, because of the contributions of a Japanese and a Chinese botanist, records of the wood of the more extensively cultivated species are available. In 1921 Kanehira (5, 6) published two articles on the anatomical characters for the identification of the wood of Japan and of Taiwan. In these publications he gave detailed accounts of the wood of *P. tomentosa*, *P. kawakamii* and *P. fortunei*. His material for the first species was from Japan and that for the other two species was from Taiwan. In 1932 Tang (10) reported on the identification of some important hardwoods of South China. His wood samples were collected from northern Kwangtung Province of China.

According to these authors the paulownias have light soft smooth wood which is rather incombustible, difficult to split and does not absorb moisture readily. The grain is straight or close and the texture medium. The color varies between species, and between samples collected from different places. In general *P. fortunei* and *P. kawakamii* have lighter wood which varies from grayish white to gray or pinkish brown. The wood of *P. tomentosa* is yellowish gray or light brown.

Microscopically the wood is ring-porous in *P. tomentosa* and *P. kawakamii* and ring- or diffuse-porous in *P. fortunei*. The radial diameters of the pores are 80-200 μ in *P. tomentosa*, 100-300 μ in *P. kawakamii* and 200-400 μ in *P. fortunei*. The lengths of the vessel segments and the wood fibers are 200-400 μ and 500-1,200 μ in *P. tomentosa*, 150-400 μ and 550-700 μ in *P. kawakamii* and 280-450 μ and 800-1,700 μ in *P. fortunei* respectively. The wood parenchyma is paratracheal in *P. tomentosa* and both paratracheal and metatracheal in the other two species. The pith rays are nearly homogeneous or heterogeneous.[1]

The specific gravities of the wood of different species vary from 0.23-0.30 in *P. tomentosa*, 0.33 in *P. kawakamii* to 0.40 in *P. fortunei*.

In 1951 Romeka (7) reported some observations on the physical properties of the wood of *P. tomentosa*. Regarding the workability he remarked:

> "The planer will put a smooth finish on a board without danger of chipping. A very heavy cut can be made without slowing down the machine or spoiling the finish.
>
> "The jig saw and band saw exert little effort cutting this wood. Complex lines can be followed easily where other kinds of wood give trouble. The jointer cuts square, true corners on Paulownia at any speed. There is no chipping on the edges when rabbeting is done.
>
> "Initial shaping on a wood lathe can be done by taking heavy cuts with a sharp chisel without danger of cracking or splitting Paulownia wood. . . . This wood has an open grain resembling chestnut. A wood sealer is necessary to fill the pores before applying the finish. A first rate job was accomplished on Paulownia for lathe with a glue proven to be unsatisfactory on other kinds of wood.
>
> "Paulownia is an excellent wood for carving and for work with hand tools. It does not split easily. A wood chisel one-half inch in width was driven lengthwise through a block (2"x3"x4") without splitting the wood. Pilot holes are not necessary to drive screws while flat headed screws can be driven flush with the surface."

Regarding the drying property Romeka reported that experiments of drying paulownia wood in the kilns on the mahogany and poplar schedules have been performed by the Texas Land and Lumber Company of Texas, Maryland. Paulownia dries faster than both mahogany and poplar. In another test one inch boards of paulownia were placed in the kiln on the last day of an oak schedule with a temperature of 180° F and the humidity of 128%. After 12 hours the boards were unharmed and the wood had a 24% moisture content. Under the same treatment poplar would have cupped badly and cracked at the ends, oak would have checked and honey-combed and wood of other kinds would have been severely damaged. Romeka also remarked that in a room of normal living temperature the paulownia wood can dry to 10% moisture within 25 days. This ability to dry rapidly in open air eliminates the need and expense of drying paulownia wood by kiln.

In China it is a well known fact that the paulownia wood is resistant to wood decaying fungi. Chen in 1049 A.D. (1) reported that in the construction of houses the paulownia beams and pillars last much longer than pine, fir or oak. In this re-

[1]For detailed descriptions and measurements the reader is referred to the original publications of Kanehira and Tang (see bibliography) or Hu's *A Monograph of the Genus Paulownia*.

spect Romeka observed that a large branch of a poplar and a paulownia log about 12 inches in diameter were left in the forest for five years. The poplar rested two feet off the ground while the paulownia lay flat on the forest leaf-litter. With the exception of the central core two inches in diameter, the poplar was soft and decayed. The surface of the paulownia log was bleached and weathered to a depth of one-eighth of an inch but it showed no sign of decay except a small area of 18" x 12" where it contacted a decayed stump. This spot was soft and slimy up to one inch deep. After this incidence Romeka remarked that although heart-rot is prevalent in growing paulownias, the wood shows extraordinary ability to withstand wood-rotting fungi when dry.

POTENTIAL WOOD USES

Stearns in 1944 published an article advocating paulownia as a tree of commerce. In this article he maintained that the paulownia wood is about two-thirds as heavy as the lightest commercial wood in the United States. He remarked that with the specific gravity of 0.23-0.30, a cubic foot of paulownia wood weighs 14.37-18.75 pounds while the lightest northern white cedar weighs 22 pounds a cubic foot at twelve percent moisture content. He further stated: "One particular use would be the manufacture of crating and boxing lumber for airplane express or freight shipments. We are on the threshold of a great aeronautical age and a large part of this business will be air freight. . . . Where it takes thirty pounds of ordinary box lumber to crate a given object, the same container could be made with eighteen pounds of paulownia—forty percent saving in weight and shipping expense of the container."

Another potential utilization is in the field of commercial veneer. Of this subject Romeka made some preliminary tests. He reported that paulownia wood cuts smoothly on a rotary lathe or vertical slicer without preheating treatment. The veneer so produced dries easily without buckle or crack and it is trimmed with no tearing or splintering along the edges. It glues well into plywood and holds the glue bond with extraordinary tenacity. He thus suggested the use of paulownia as a substitute for balsamwood in the preparation of military aircraft plywood. This would eliminate many difficulties in laminating a hardwood face to the core. Stearns on the other hand suggested the use of paulownia to substitute for chestnut cores in veneer panels. He further remarked, "A reforestation program aimed at the production of a new lightweight lumber source would be worth while. Many of our lightweight wood problems might be solved by the success of such an enterprise." A manufacturer of mahogany plywood boats estimated that a boat made of paulownia plywood would finish at approximately 60% of the gross weight of his product.

Another possible use of paulownia wood is for carving. It is excellent for work with hand tools. It would be an ideal wood for use in the school shop.

The charcoal made of paulownia is used in the best fireworks.

Investigation into the possibilities of supplying pulp in the paper industry was made by Romeka. He concluded that paulownia produces a fair pulp and it may have some place in paper manufacture in the future. He also made some tests into the properties of paulownia chips as bedding in dairy barns or litter in chicken houses and found that they have great advantages over the hardwood chips now used on the farms. First the paulownia chips have round and smooth edges. They are light and they retain 174% more water on weight basis than ordinary hardwood chips. He remarked that paulownia chips are superior for use as plant mulch.

THE BOTANY OF PAULOWNIA

In the last fifteen years more and more progressive American foresters have be-

come aware of the virtures of paulownia wood, have visualized its modern potentialities and have begun to search for the source material so that future demands might be supplied. The species of *Paulownia* are native to China and the flora of China has been my special field of concentration. Incidentally, I have been asked to list the known species of the genus and to provide a key for their identification.

Paulownia is one of the earliest genera described from eastern Asia. Two of the most important early post-Linnaean publications in the botany of eastern Asia are Thunberg's *Flora Japonica* and Loureiro's *Flora Cochinchinensis*. The first work was published in 1784 and it covers the plants of the temperature region of eastern Asia and the second work published in 1790 covers the plants of the tropical region of the same sector. A species of Paulownia was described in Thunberg's work. It was named *Bigonia tomentosa*. In 1841 Steudel transferred this species into *Paulownia*. From this time on up to 1938 eighteen species and three varieties of *Paulownia* were described from China. A careful study of the existing records reveals that many of these species were described on the strength of unreliable characters of fragmentary specimens. Consequently many superfluous names were established and a confusion in the classification of the species and varieties was created. In a monograph of the genus *Paulownia* the total number of species was reduced to six and their key characters are as follows:

A. A Key to the Species

A. Flowering twigs pyramidal with progressively smaller branches (Fig. 1, a) or cylindric with simple or dichotomous cymes only (Fig. 1, b); cymes loose, 3-5-flowered, the peduncles almost equal the pedicels; capsules various in shape and size.

B. Capsules subglobose-ovoid (figs. 3-5); pericarp cartilaginous or crustaceous; corolla digitaliform (except in *P. elongata*, fig. 3).

C. Dendroid hairs on the lower surface of the leaves on elongated stalks and the branches capillary (Fig. 2, a); corolla with straight articulate hairs; leaves on mature branchlets ovate-cordate and on vigorous branchlets angular or lobate *P. tomentosa*

CC. Dendroid hairs on the lower surface of the leaves subsessile or sessile, the branches short and stout (Figs. 2, b-c); corolla glandular-pilose or dendroid and glandular-pilose.

D. Mature leaves cordate-ovate, almost glabrous with few scattered dendroid hairs on rather short stalks beneath; calyx deeply lobate, the tube equal or shorter than the lobes; corolla digitaliform, glandular-pilose. *P. glabrata*

DD. Mature leaves elongate ovate-cordate, the apical end long produced (Fig. 5); calyx obconic, shallowly lobate, the tubes twice as long as the lobes; corolla subinfundibuliform, with dendroid and glandular hairs. *P. elongata*

BB. Capsules oblong-ellipsoid (Fig. 6), rarely subovoid, and constricted at the base; pericarp woody; corolla subinfundibuliform, 8-10 cm. long, gradually attenuating towards the base; calyx becoming partially glabrous at anthesis, the tube obconic, much attenuate at the base. *P. fortunei*

AA. Flowering twigs with stout lateral branches similar to the central one (Fig. 1, c and Fig. 4); cymes subsessile or umbelliform; peduncles of cymes very short or wanting; capsules subglobose-ovoid.

B. Corolla subcampanulate, 3-4 cm. long, the tube villose; leaves collected at anthesis hirsute beneath. *P. kawakamii*

BB. Corolla digitaliform, 5.5 cm. long; leaves collected at anthesis lanate, the hairs dendroid, on long-stalks. *P. fargesii*

B. Morphological Peculiarities

In the identification of the species of *Paulownia* one must remember the morphological peculiarities and morphogenetic possibilities of the group. Otherwise, one

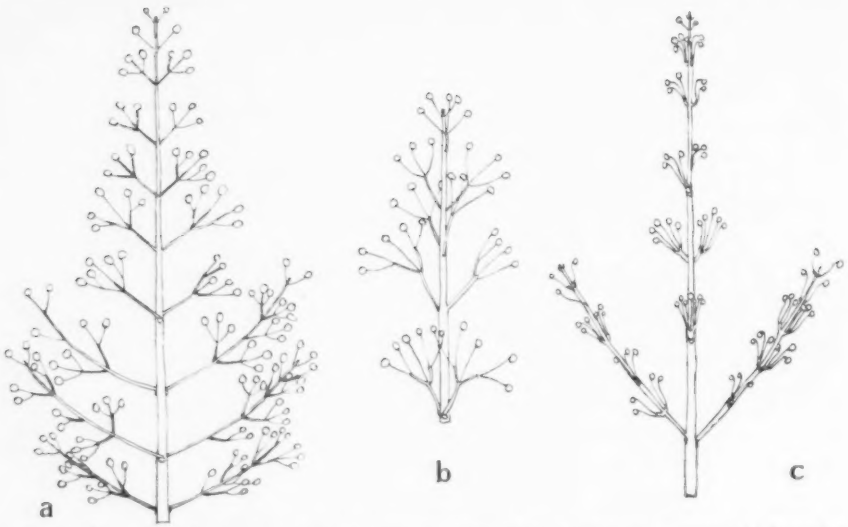

Fig. 1. Types of inflorescences in *Paulownia:* a. Pedunculate thyrses on a pyramidal flowering twig (*P. tomentosa*). b. Pedunculate thyrses on a cylindric flowering twig (*P. fortunei*). c. Subsessile or sessile thyrses on flowering twigs with stout lateral branches (*P. kawakamii*).

may be misled by the dimorphic conditions occurring at different stages of development of the parts of the species in question.

Habit. The species of *Paulownia* are fast growing trees which do not have a strong tap root system. The root-branches are horizontal and shallow. They are capable of producing adventitious buds which give rise to sturdy and vigorous saplings. The trunks of the trees are gray, smooth, often crooked and provided with adventitious sprouts which have larger, more angular and less pubescent leaves. The branchlets are stout, devoid of terminal buds, conspicuously lenticellate, very rich in central pith and have slightly elevated suborbicular or oblong leafscars. The axillary buds are partially covered by the epidermal tissue.

The paulownias have a very unusual growth habit. A mature branchlet which bears flowering buds in the axils of its progressively diminutive leaves may be developed from a bud located at a considerable distance below the flowering portion of a twig or it may be produced from a subterminal axillary bud of last year's vegetative growth. Such a bud commences to unfold during the flowering period at the time when some corollas have already dropped. At first two pairs of small rotundate scales open up and then a pair of foliaceous spathulate scales about 1-2 cm. long appears, followed by two pairs of small petiolate leaves. As growth continues the foliaceous scales and small leaves all fall off. Meanwhile six to eight pairs of progressively larger leaves are formed. In the axils of the last pair of large leaves buds which will develop into flower branches appear. After this, although the elongation of the shoot apex continues, the leaves become progressively smaller and in their axils appear branched or simple cymes. The formation of the flower buds occurs in late July or early August. In the early stage of development each young bud is subtended by a caducous, fleshy bract. By the middle of Octo

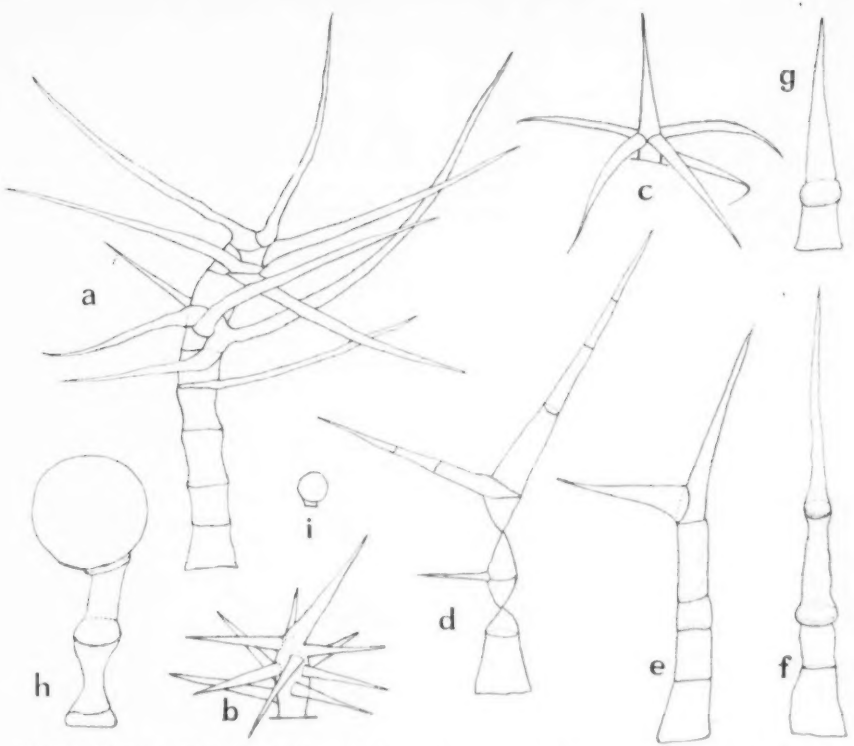

Fig. 2. Types of hairs on the lower surfaces of the leaves of *P. tomentosa*, *P. fortunei* and *P. elongata* (see text for details).

ber the flower-buds attain mature size and overwinter in this condition. After the small leaves subtending the cymes and the bracts subtending the flower-buds fall with the deciduous leaves, the naked flower-buds appear collectively as if they are in a terminal panicle. In South China as well as in Louisiana some cultivated specimens actually begin to flower in October.

Leaves. The leaves of the paulownias are normally deciduous, opposite or rarely subopposite or three on a node on vigorously growing sprouts. They are large, cordate, ovate or elongate-deltoid-ovate, entire or three to five lobed on vigorous shoots and serrate on seedlings. The size and shape of the leaves of a species vary greatly. In general a middle leaf on a mature branchlet is about half a foot in diameter. Those on immature shoots tend to be wider than long. Some leaves on a root sapling or a trunk sprout may attain one and a half feet in diameter. These leaves are less pubescent than those growing on a flowering branchlet. The leaves on the lower portion of a branchlet are less pubescent than those on the upper portion of the same twig. The diminutive leaves subtending the cymes are the most pubescent. They are usually densely lanate.

The kind of hair on the leaves of a species at similar stage of development is

quite constant. For example, the hair on the lower surface of the fifth pair of leaves in *P. tomentosa* is dendroid with capillary branches and on elongated multicellular stalk (Fig. 2, a), the hair of similar position in *P. elongata* is subsessile dendroid and with stout short branches (Fig. 2, b), and the hair on the leaf of *P. fortunei* is sessile dendroid and with rather long matting branches (Fig. 2, c).

However, the types of hairs on various leaves of a branchlet are very variable. A branchlet of *P. tomentosa* collected on August first has the following types of hairs. Taking the leaves on the fifth node as a working basis, about 90% of the hairs on the lower surfaces are multibranched, dendroid and with capillary branches on elongated stalks (Fig. 2, a). Simple or glandular hairs are not observed on these leaves. The leaves on the nodes below the fifth one are successively less hairy. The hairs on the lower surface of the second pair of leaves have fewer branches. About 10% of these have only one or two branches (Fig. 2, d-e). The hairs on the lower surface of the first pair of leaves are very diversified. About 50% of these are short erect hairs (Fig. 2, g), 15% straight elongated hairs (Fig. 2, f), 15% glandular subsessile hairs (Fig. 2, i), 5% capitate glandular hairs on elongated stalks (Fig. 2, h), and 5% straight elongated multicellular hairs with one branch each (Fig. 2, e). The leaves on the nodes above the fifth node are progressively denser in pubescence and the hairs are the multibranched dendroid type. Evidently the developing branchlet produces a substance which affects the nature of the trichomes on the stem and the leaves so that the hairs become progressively more den-

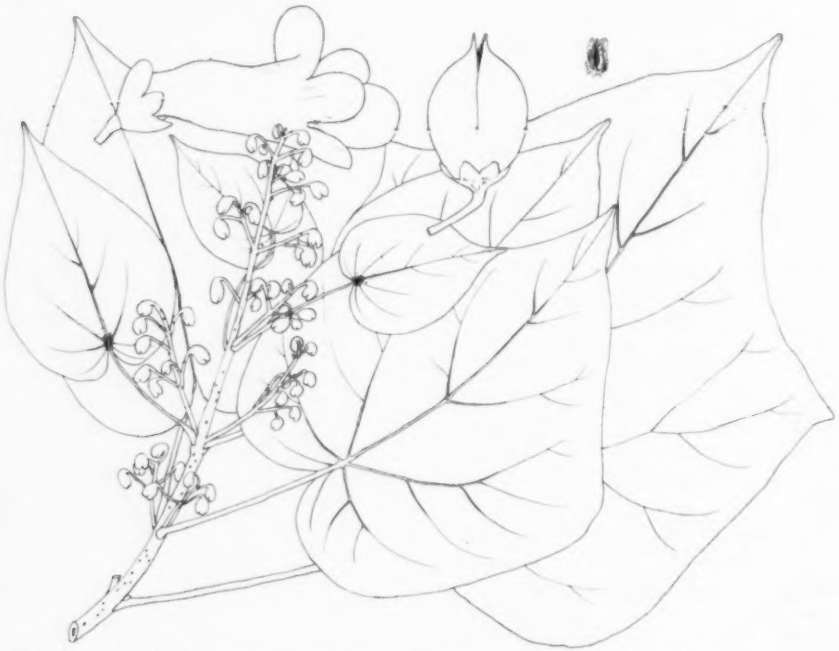

Fig. 3. *Paulownia tomentosa:* a branchlet with flower buds, a flower, a subglobose ovoid capsule and a seed.

droid and less glandular.

Inflorescences. The developmental stage of the inflorescences of the paulownias indicates that they are simple 3- or 5-flowered thyrses produced in the axils of diminutive petiolate leaves. They are formed in late July and early August and overwinter as fully developed pedicellate flower buds. When the diminutive leaves or bracts fall in the autumn, the buds appear paniculate. The type of thyrses of a species is constant. Most species have

Fig. 4. *Paulownia fargesii:* a branchlet with flower buds, a single large leaf, a flower, an ovoid capsule and a seed.

Fig. 5. *Paulownia elongata:* a branchlet with flower buds, a large leaf, a flower, and a subglobose-ovoid capsule.

Fig. 6. *Paulownia fortunei:* a branchlet with loose inflorescences, large pyriform buds, a flower with gradually attenuate corolla tube, an ellipsoid capsule, an oblong-elliptic placenta with some seeds and a butterfly-like seed.

loose pedunculate cymes (Fig. 1, a-b) while *P. kawakamii* and *P. fargesii* have sessile or subsessile ones (Fig. 1, c and fig. 4).

Flowers. Individual flowers of the paulownias are pedicellate. The pedicels are stout, densely lanate and articulate at the apical end. Many flowers or flower-buds disarticulate and fall at this joint.

The calyx is obliquely patelliform, fleshy, unequally 5-lobed and densely lanate. In *P. fortunci* the trichome is floccose and the calyx often appears partially glabrescent at anthesis. The corollas are digitaliform in most species, subinfundibuliform in *P. elongata* and *P. fortunci* and subcampanulate in *P. kawakamii*. The stamens are didynamous and the ovary is glandularly papillose. After anthesis the young fruits of some species become densely lanate.

Fruits. The fruits of the paulownias are loculicidal, ovoid or oblong ellipsoid capsules (Figs. 3-6). In *P. tomentosa* the pericarp is cartilaginous and in *P. fortunci* it is woody.

Seeds. The seeds of the paulownias are minute, each weighing about one-third of a milligram. A medium sized capsule of *P. tomentosa* contains about two thousand seeds. The seed proper is ellipsoid, about 2 mm. long, and reticulate. The seed coat consists of two cell-layers, an inner layer of thick-walled lignified cells and an almost transparent outer layer expanded into wing-like outgrowths. With the wings some seeds resemble the swallow-tail butterfly (Fig. 6). The paulownia seed requires a certain amount of light energy for germination. It can not germinate in darkness.

Seedlings. The minute size of the seed

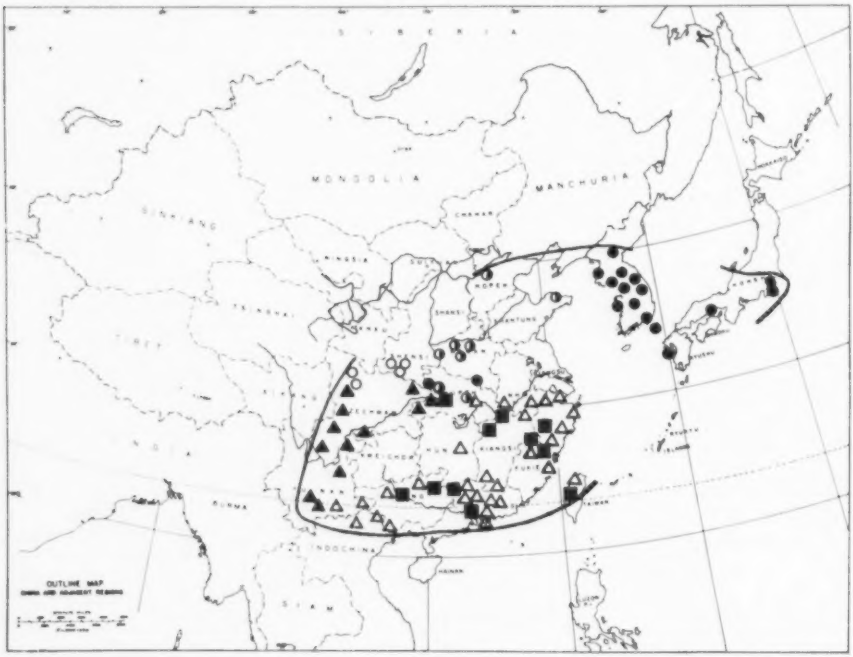

Fig. 7. The range of *Paulownia* in eastern Asia and the distribution of species: ● *P. tomentosa* and variety, ◑ *P. elongata*, ○ *P. glabrata*, ▲ *P. fargesii*, △ *P. fortunci*, ■ *P. kawakamii*.

does not provide much food reserve for the seedling. Naturally the seedling is unusually small and delicate. Its slender primary root is not strong enough to penetrate the litter of the forest floor. This is probably the reason of the occurrence of the paulownias in city dumps or disturbed areas in nature.

C. Phytogeographical and Ecological Notes in Relation to Cultivation

The virtues of the wood of the paulownias warrant experimentation with the aim of large scale cultivation of some species as a source of supply for lightweight lumber. Successful sylvicultural management of paulownia forest depends directly upon our knowledge of the geographical and ecological requirements of the species. In this field very little information is available. Much research awaits scientific investigations. However, the data on the phytogeographical conditions in the homeland of various species of *Paulownia* and the ecological notes accompanying many specimens are valuable references.

The geographical distributions of the six recognized species are illustrated in figure 7. With the exception of the data concerning the Korean sector, the map is constructed on the basis of specimens examined in the Herbarium of the Arnold Arboretum and the Gray Herbarium. Information about the distribution of the species in Korea is adapted from a map of Kamamoto's *Illustrated Forest Plants of Korea* (4).

Range of the genus. The range of the entire genus assumes a slightly deformed elliptic shape extending in a southwest-northeastern direction between Long. 100-140°E and Lat. 22-40°N. Based on our knowledge of the flora of this region we know that the half circles and dots on the upper and right hand side of the map beyond the 34th parallel all represent material collected from cultivated specimens. It seems evident that the area lying between Long. 105-115°E, especially along the 30th parallel, represents the area of the concentration of species for the genus. All the six recognized species are found there. It is worthy of note that this area is very rich in relic tree species. Many of the well known "living fossils" such as the *Metasequoia, Cercidiphyllum, Ginkgo, Liriodendron*, etc. occur there. Topographically the area is a river-gorge country with rice fields in the valleys and coniferous forests over the upper slopes of the mountains and much disturbed mesophytic forests in between. The average temperature in January is 2-4°C and the annual rainfall is 1,000-1,250 mm. falling predominantly in summer. In this area paulownia is a minor element of the deciduous mesophytic forest. Spontaneous specimens have been reported as isolated individuals in the marginal areas of the forest. They are usually situated on moist and well-drained steep ravines or open valleys where they are associated with species of *Acer, Fraxinus, Quercus, Castanea, Tilia, Pinus, Cunninghamia*, etc. When the environment is modified by human activities and the natural vegetation destroyed the species may also be found in thickets or open grassy slopes.

The large number of small winged seeds which germinate readily and the ability to survive fires through the formation of adventitious root buds give the paulownias unusual competitive power and render them the pioneers in newly disturbed areas. The requirement of certain light quality for germination and the small size of the seed with little food-reserve are probably the contributing factors for the isolated occurrence of the trees in nature. When a wind-blown seed of paulownia reaches an open area caused by a landslide or the falling bank of a river it soon germinates. The fast growing habit of the seedling allows it to keep ahead of the less aggressive and more shade tolerant species and to get established. It takes about eight to ten years for a paulownia tree to reach the flowering stage. By the

time this new tree is ready to disperse its seeds the more shade-tolerating trees, shrubs, lianas and herbaceous forms have become firmly established. They have modified the physical environment to such a degree that no more paulownias would have any chance to get established. Moreover, if some seeds do germinate the root of the young seedlings are so delicate that they can not penetrate the litter on the forest floor and they gradually die.

It is indisputable that climatic conditions are the most important factors circumscribing the northern limit of the range of the genus. Figure 8 shows the mean temperature in January in eastern China. When this map is superposed on the distributional map of *Paulownia*, it reveals that most of the spontaneous species occur south of the January isotherm of 0°C. Beyond this limit decreasing precipitation, longer and more frequent droughts, shorter growing seasons and low winter temperature eliminate the genus from the natural flora. However, cultivation has extended the range of *P. elongata* five degrees northward in the coastal region. It is interesting to note that the northern limit of the range of *Paulownia* is almost the same as that of *Ilex*, another genus common in the mesophytic forest of China. However, in *Ilex* the montane species extend westward into northern India and the tropical species extend southward into Malaya, Sumatra, Java and Borneo. In *Paulownia* the southern limit of the range stops about the 22-parallel in southeastern Yunnan and northern Tonkin in Indo-China. In this area the species of a very closely related genus *Wightia* occur and extend thence westward to northern India and southward to Malaya and Indonesia.

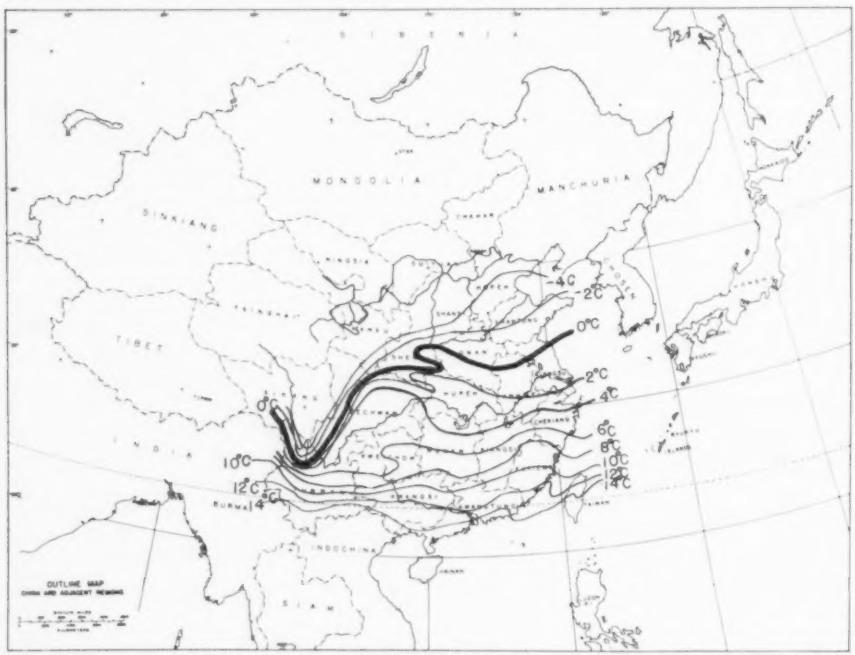

Fig. 8. The mean temperature in January in the paulownia region of China. The dark line indicates the January isotherm of 0°C. South of this limit the paulownias grow spontaneously.

Distribution of individual species. The map demonstrates that there are well-marked ranges of the southern and the northern species. The southern species do not extend northward beyond the 32nd parallel. These are *P. fortunei* and *P. kawakamii* in the east and *P. fargesii* in the west. The northern species are hardier and they occur along the Tsingling Range and thence they extend northward to the 40th parallel. These are *P. tomentosa* and *P. elongata* in the east and *P. glabrata* in the west.

Paulownia fortunei is the most widely distributed species of the genus. Herbarium specimens substantiate its occurrence in nine provinces. These specimens were collected between altitudes of 370-2,000 meters. In eastern China, Chekiang Province, this species attains an enormous size. It reaches 27 meters in height and its trunk is 2 meters in diameter. *P. kawakamii* is another eastern species which occurs in seven provinces at altitudes varying from 300 to 1,000 meters. *P. glabrata* is limited to the Min River valley in northwestern Szechuan and to southern Shensi. There it occurs at altitudes of 350-1,700 meters. This species resembles *P. tomentosa* in its digitaliform corolla covered with straight articulate and glandulose hairs and in its ovoid capsules. Further investigation and more material may prove this species a glabrescent western form of *P. tomentosa*. *P. elongata* is a northern form resembling *P. fortunei* in the type of trichomes and in the shape of the corollas. However, its ovoid capsules are very distinct. It is a native in the mountains of western Honan Province and it is now widely cultivated in northern China where the annual rainfall is about 250-750mm. Evidently it is not only the most hardy species of the paulownias but it is also a drought tolerating one. Our limited number of Chinese specimens of *P. tomentosa* were collected from Central China. The Japanese and Korean records of the same species are all from cultivated specimens.

The records of the distributions of different species of *Paulownia* seem to point out that areas for successful large scale cultivation of the paulownias should have a minimum January temperature of 0°C and an annual rainfall of 1,000mm. It is also noteworthy that the paulownias are best fitted for plantings in exposed situations. It would be highly profitable to use different species of the genus for reforestation on bare lands.

ACKNOWLEDGEMENTS

Dr. Robert C. Foster of the Gray Herbarium, Harvard University kindly read this manuscript and gave many helpful suggestions. Without the encouragement of Dr. David J. Rogers of the New York Botanical Garden this article on the economic botany of the paulownias would not have been prepared. To these gentlemen I wish to express my grateful appreciation.

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Gamma Radiation Effects on Fruits and Vegetables[1,2]

Several million dollars are lost in the United States each year as a result of post harvest diseases of crops. Claim costs to railroads alone in 1958 amounted to $11 million. This work demonstrates that it is possible to extend the shelf-life of fresh fruits and vegetables at room as well as at refrigeration temperatures by gamma radiation, by surface pasteurization, sprout inhibition, and also by retarding the ripening processes. The information presented should be useful to researchers, shippers, packers, and processors.

D. K. SALUNKHE[3]

INTRODUCTION

The food supply is subject to heavy losses in operations of production, transportation, and subsequent storage through bacterial, fungal, and enzymatic decomposition. It has been estimated that nearly one-third of the produce harvested is never consumed, due to spoilage. This spoilage amounts to many thousands of tons of fruits and vegetables. As a result, more than a billion dollars is lost annually in the U.S.A. alone to growers, packers, shippers, and processors. Evidently, there is a great scope for devising measures to control these losses. These can be reduced substantially in various phases from harvest until the produce reaches the consumer's table. Several methods—prepackaging treatments, packaging methods, storage sanitation, and low temperatures —are used to minimize these losses, to extend the storage life, and to retain the quality of fresh fruits and vegetables.

Atomic energy for peaceful uses presents a multitude of possibilities in food preservation. The fission products and machine-produced ionizing radiation (Figure 1 shows the schematic spectrum illustrating the electromagnetic radiation) will therefore play important roles in research and technological development in food preservation. The potential value of radiation to food preservation is unlimited and hardly touched.

Radiation from radioactive material is a stream of fast-moving particles or waves which comes from atoms. Man-made radiation in the form of X-rays was discovered in Germany by Roentgen in 1895. In France, a year later, natural radioactivity was first identified with uranium by Becquerel. Invisible rays from radioactive elements were found to be of three kinds, namely—alpha, beta, and gamma. The alpha particle is identical with the nucleus of the helium atom. A sheet of paper can stop it. The use of it, in food preservation therefore, is not feasible. The beta particle is the same as an electron and negatively charged. It has a little more penetrating power than the alpha particle, but a thin sheet of metal will restrain it. However, it could successfully be utilized in the surface pasteurization of many foods. The gamma ray is not a particle. It is a non-corpuscular electromagnetic radiation of extremely short wave length. It is similar to X-ray and is a highly penetrating ray. Hence, it has tremendous possibilities in pasteurization as well as in sterilization of foods.

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[1]Research conducted at the Utah State University in cooperation with the Quartermaster Food and Container Institute for the Armed Forces and has been assigned No. 1082 in the series of papers approved for publication. The views and/or conclusions contained in this paper are those of the author. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

[2]Contribution No. 167 from Utah State Agricultural Experiment Station, Logan, Utah.

[3]Department of Horticulture, Utah State University, Logan, Utah. Received for publication 2 November, 1960.

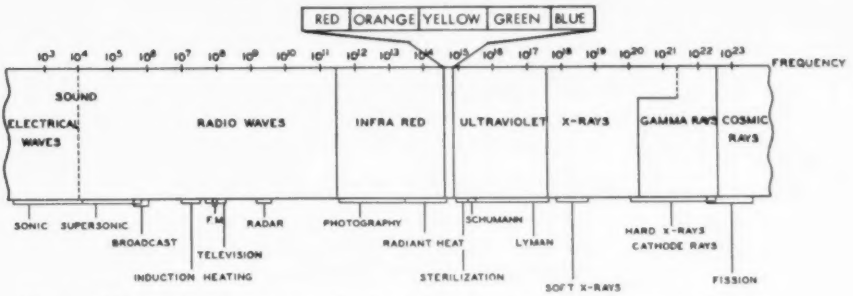


Fig. 1. Relationship of various types of radiations in the electro-magnetic spectrum.

Radiations, beta as well as gamma, have shown promise of making important peaceful contributions to the development of improved control measures against insect and microbial growths which would ultimately improve the food supply situation. Thus, the destructive characteristics of radiation (Figure 2) can be utilized to eliminate insect infestation, sprouting of tubers, bulbs, and roots, and microbial populations on many foods. A particular advantage that irradiation offers is that it does not appreciably raise the temperature of the food during the treatment. Thus, perishable fruits and vegetables can be preserved in their fresh state.

This paper presents a review of earlier published work and results of extensive studies conducted from 1955 to 1959 at the Utah State University on effects of gamma radiation dose,[4] rate,[5] and temperature during radiation and pre-radiation packaging treatments on storage life and quality of 22 fruits and vegetables.

REVIEW OF EARLIER INVESTIGATIONS

Control of Sprouting and Insect Infestations

Pioneering investigation on the influence of ionizing irradiation on potatoes

[4]The unit of radiation, the roentgen (r), is the quantity of electromagnetic radiation which produces one electrostatic unit of charge of either sign per cubic centimeter of dry air at 0°C and at standard pressure. This electric charge is produced by the formation of ion-pairs through the combined mechanisms of the photo-electric effect, Compton scattering, and pair production.

In an attempt to define a unit which would describe the absorption of energy in media other than air, the roentgen-equivalent-physical (rep) was originally established as 83 ergs per gram of a biological material. This unit is equal to the energy absorbed in air in a field of one roentgen. However, it was later found that one roentgen of moderate energy photons results in the absorption of 93 ergs per gram of tissue in order to achieve equivalence with the roentgen in that medium. However, literature references have used either definition, and a great deal of confusion has arisen over the use of the rep. It can never be considered equivalent to the roentgen, and is numerically equal to it only when defined for a given material.

In an attempt to eliminate confusion in the use of radiation sources, the International Commission on Radiological Units recommended the use of the *rad*, which does not refer to a specific medium. The *rad* is equal to the unit of absorbed dose and is 100 ergs per gram of the irradiated material. It is now considered best to do this on the basis of the total energy absorbed in the material rather than the amount of ionization taking place. (As recommended by the Sixth International Congress of Radiology in 1950, the dose is expressed as follows: "For the correlation of the dose of an ionizing radiation with its biological or related effects, the International Commission on Radiological Units recommends that the dose be expressed in terms of quantity of energy absorbed per unit mass (ergs per gram) of irradiated material. For this reason, the radiation dose is expressed in rads rather than r or rep in the studies conducted at the Utah State University.")

[5]Rate of radiation is usually expressed in roentgens, reps, or rads per hour, thus, expressing the rate at which ions are being produced by the radioactive source. For gamma radiation, it is denoted by the rate at a given distance from the source.

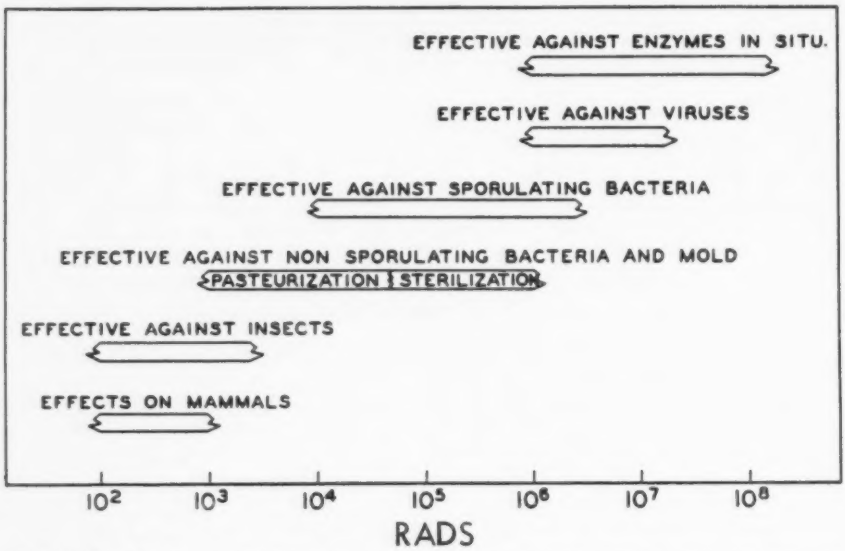


Fig. 2. Lethal doses of radiations on mammals, insects, bacteria, fungi, viruses, and enzymes.

by Sparrow and Christensen (106) created considerable interest in the utilization of radiation to increase the storage life of potatoes and other root and bulb crops. Their observations on the inhibition of sprouting were confirmed by numerous workers (12, 13, 14, 15, 17, 20, 22, 23, 24, 26, 36, 37, 38, 39, 40, 56, 57, 63, 64, 65, 73, 96, 97, 98, 99, 101, 103, 107, 109). Concomitant with sprout inhibition, weight loss, and shriveling were reduced (56, 57, 109). However, periderm formation was prevented by the 20 and 80 kilorep (1 kilorep = 1000 reps) (107) and suberin development, although retarded initially by radiation, soon compared favorably with controls (13). The dose requirements for sprout suppression varied from crop to crop (56, 57) and also from variety to variety within a given crop (109). Irradiated crops remained free from decay for long periods when not subjected to excessive handling.

Dallyn and Sawyer (22) showed that fast electron irradiations were effective in controlling sprouting and rooting of onions only when irradiated directly on the base of the bulb, which killed the growing points. The irradiations at 20 kilorads (1 rad = 1.075 rep) completely inhibited rooting and external sprouting. Proctor et al. (82) found that the insect infestations can be controlled successfully by doses less than 1×10^3 rep.

Control of Microbial Growth

Beta and gamma radiations with doses in 1 to 5×10^5 rads range have been shown to retard the growth of spoilage organisms such as bacteria and fungi for appreciable periods of time (2, 3, 4, 5, 6, 7, 9, 11, 14, 15, 18, 19, 21, 25, 27, 33, 36, 37, 38, 41, 43, 44, 50, 51, 53, 59, 62, 67, 68, 70, 76, 78, 81, 83, 85, 86, 88, 92, 93, 95, 100, 104, 105). Objectionable radiation side effects such as flavor, texture, and color changes are generally small in 1 to 3×10^5 rads ranges (7, 15, 21, 27, 53, 56, 57, 67, 76, 86, 91, 92, 95, 104). Hence, low dose radiation process has been considered as a useful tool for extending shelf-life of fresh foods, par-

ticularly when used in conjunction with refrigeration and other auxiliary methods of preservation.

Beraha et al. (3, 6), Cooper (21), and Dhaliwal (25), have shown that the mold damage caused by *Botrytis* occurs widely on fresh fruits and seriously limits the storage duration after harvest. However, gamma as well as beta radiation appreciably retards the growth of this mold for a period of up to 15 to 20 days by a dose of 2×10^5 rads. The retardation at the 4×10^5 and 8×10^5 rads levels extends well over 20 to 25 days. Box (7), Cooper (21), Eukel and Huber (27), showed that Shasta strawberries irradiated at 2×10^5 rads with gamma and beta rays and stored at 40° and 68° F; the non-irradiated controls were heavily moldy after 2 days' storage at 68° F and after 10 days' storage at 40° F. However, the irradiated strawberries were not moldy and were in excellent marketing condition. Mold damage caused by *Sclerotinia*, blue molds (*Penicillium digitatum*, *P. italcum*), Black and Brown rots (*Botrytis*), and Leak (*Rhizopus nigricans*), on most of the fruits has been successfully controlled with electron doses up to 3×10^5 rads. Irradiation with a high energy electron beam capable of penetrating the objects rather than only the area at which microflora is present does not seriously influence the overall quality of the food. Thus, it appears that processing with a high energy electron beam may eliminate much of the cumbersome handling detail which is necessary to expose multiple randomly distributed infected areas when a low energy electron beam of limited penetration is used (25, 62).

Brownell et al. (14), Cooper (21), Dhaliwal (25), Proctor et al. (83), Rivers (86), and Salunkhe et al. (92, 95) reported processes in which gamma radiation is combined with refrigeration, heat, and anti-fungal chemicals, and they have proposed to increase the storage life of cooked meats, fresh and blanched fruits and vegetables, and other food items packaged in plastic bags. Loss due to spoliage of fresh produce could be eliminated if retail sales were made within a few weeks. Eukel and Huber (27) give the cost calculations based on operation of facility and indicate that cost of a commercial operation in the order of 0.5 cents per 0.25 mega rad (1 mega rad = 1,000,000 rads) pound for fresh fruits and vegetables.

Ionizing irradiation of potato tubers inhibits sprouting in storage and has been suggested as a means of prolonging the storage life of tuber, bulb, and root crop. However, such treatment has resulted in rot problems. Radiation intensities of 15 kiloreps and above predispose tubers to rot. Wounding of tubers before or after irradiation increases incidence of rot over non-wounded tubers. Incidence of storage rot in wounded and non-inoculated tubers was highest at the high levels of radiation intensity (26). The importance of storage rots in tubers exposed to ionizing irradiation has been emphasized by Heiligman (39), Hooker and Duncan (40), Schreiber and Highland (99). Mukhin and Panasenko (65) reported inoculation studies on irradiated tubers injected with *Phytophthora infestans*. They noted increased infection if inoculation followed radiation over that when inoculation preceded radiation.

Burns (16) found that irradiated tomato fruits inoculated with *Eracinia aroidae* exhibited a more rapid rate of decay after a dose of 1×10^6 rads as compared to the inoculated controls. According to Nehemias et al. (67), peaches and cherries packaged in polyethylene bags underwent a more rapid rate of spoilage after irradiation. These workers hypothesized that radiation caused either physical or chemical change in the fruit enabling mold to grow more rapidly. Hooker and Duncan (40) have shown that potatoes inoculated with causal agent of fusarium dry rot and bacterial soft rot decayed

more quickly than inoculated controls. Their data showed that as the radiation dose was increased to 135 kiloreps, the average rate of growth was between three and four times more rapid than in the non-irradiated tissue. Beraha et al. (4) observed that potatoes which were inoculated with *Pythium debaryanum* showed increased susceptibility to decay by this organism after irradiation when compared to the non-irradiated controls. Fields et al. (28) conducted a study of the growth of *Aspergillus oryzae* in irradiated components of foods. The growth of *Aspergillus oryzae* was found to be significantly higher on irradiated glucose-asparagine and glucose when these materials were grown in these media. Nehemias et al. (67) showed by increasing the radiation doses, the number of organisms present on products decreased. However, an apparent anomaly existed. One explanation might be that radiation causes changes in the fruit which enable the mold to grow readily. This effect at lower than 1×10^6 rads doses stimulates growth rates to more than compensate for the fact that fewer organisms are present initially. At doses above 1.5×10^6 reps, undesirable changes have been observed in most fruit independent of the rate of mold formation. Peaches turned brown; cherries became mushy; and undesirable off-flavors developed. Phillips (75) indicated that irradiation produced organic acids from glucose. The production of such acids might stimulate fungus growth on the irradiated foods.

Burns (16) suggested that irradiated tomatoes rotted more than the controls because of depolymerization of pectin found in middle lamellae. Roberts and Proctor (87) and Salunkhe (89) have shown that the middle lamellae of potato tubers was altered by doses of 1000 kiloreps and above. Hooker and Duncan (40) have also advanced the theory that weakening of the plant tissue may increase the susceptibility of potatoes to spoilage.

Quality Changes

Flavor. Licciardello et al. (54) showed that the sterilized products with irradiation when stored at 50° and 68° F were acceptable after 10 months' storage. Deterioration in quality occurred within one month when samples were stored at 125° F. However, Groninger et al. (35), Pratt and Ecklund (77), calculated a statistical analysis of taste test scores which showed significant off-flavor in each of the irradiated meats and vegetables in sterilized dose levels. In every case, important changes in appearance and flavor developed on storage. Some of these changes might be attributed to enzymatic action. It can be noted from Figure 2 that the radiations can not inactivate enzyme systems even at high doses which is one of the major problems in the use of radiations in food preservation. It was possible to extend the storage life of spinach held at 36 to 40° F by preliminary blanching to inactivate enzyme systems and then packing in hermetically sealed containers and irradiating with high-voltage cathode rays at 1.5×10^6 reps. It was found that the radiation-induced flavor diminished progressively as the storage duration advanced (92) and by the use of free radical acceptors and interceptors prior to irradiation (42, 50, 79, 80), the off-flavors were reduced. The flavor development was also dependent upon the packaging media and packaging methods (93). However, irradiation of potatoes (73), onions (22, 23, 24, 97), carrots (56, 57), and many other fruits and vegetables (76, 92, 95), produced no detrimental effects on flavor when irradiated at the low doses.

Texture. Studies conducted by Al-Sammarai (1), Boyle et al. (8), Brownell et al. (13), Burns (16), Glegg et al. (32), Glegg and Kertesz (30, 31), Hannan (36), Hooker and Duncan (40), Kertesz et al. (45), Khenokh (46, 47), Madsen (56), Madsen et al. (57), McArdle and Desrosier (60), McArdle and Nehemias (61), Phillips (75), Salunkhe

(89, 90), Salunkhe et al. (91), Salunkhe and Moser (94), and Schwimmer et al. (102) ound that complex components of foods such as proteins, fats, carbohydrates—starch, sugar, inulin, cellulose, and pectins—were degraded to their simpler components. This degradation of some of the compounds has been attributed to the softening of foods. However, when the product is irradiated in the vicinity of 2 to 3 $\times$ 10^5 rads, no unacceptable softening was found.

Color. The destructive effect of ionizing radiations upon green color of vegetables has been noted by Hannan (37) and Salunkhe (89). The destruction of chlorophyll in a number of cathode ray irradiated green vegetables was reported by Nickerson et al. (69). A linear decrease in chlorophyll content of green beans and broccoli resulted from increases in gamma radiation dose over the range of 0.49 to 9.29 mega rads (108).

Huber (41) used a capacitron electron accelerator to produce sterilizing dosages and reported considerable bleaching of carrots and some bleaching of green beans. Lukton and MacKinney (55) studied the breakdown of carotenoids by gamma irradiation in a number of products. The destruction of carotene and xanthophyll upon irradiation ranged from 5 to 95% in broccoli, 3 to 20% in sweet potatoes, and 0 to 5% in carrots. The temperature of irradiation, packing media, and headspace of gas all had effects (29).

The strawberry and sour cherry anthocyanin pigments are sensitive to ionizing radiations (58, 91). Markakis (58) reported that 0.365 mega rads of 2 Mev cathode rays destroyed 55 per cent of the pigment, and dehydration of the juice further increased the radio-resistance of the pigment. The strawberry anthocyanin is more radio-sensitive in pure pigment solutions than in original juice. Addition of sucrose to juice increased the pigment destruction by gamma radiation. Strawberries, when irradiated with 2 Mev cathode rays and also with gamma rays, increased bleaching of the fruit as the dose of irradiation increased from 0.093 to 3.72 $\times$ 10^5 rads (58, 91). Slower dose rates appeared to be more detrimental to the dye solutions and to pigment developments than faster rates (10, 86). Potatoes (56, 57), lima beans (89), Jerusalem artichoke tubers (90, 94), and starch suspensions and other foods (46, 47, 71), became darker and progressively browner as the radiation dose increased over 0.93 $\times$ 10^6 rads. According to Naik-Kurade et al. (66) the irradiation-induced browning differed from heat-induced browning in that the former involved the formation of reductones as intermediates while the latter involved 5-hydroxymethyl furfural and aldehydes which appeared to be destroyed by ionizing radiation. The reductones were capable of contributing to darkening when systems were subjected to post-irradiation heating.

Nutritive value. Nickerson et al. (69) showed that 64 to 92% loss of vitamin C in asparagus, broccoli, green beans, and spinach was found. Proctor and O'Meara (84) also showed that high-voltage cathode radiations caused some loss of ascorbic acid in solution and to a lesser extent in orange juice. Brownell and associates (13) maintained that even radiation of 10 kiloreps reduced the ascorbic acid content of potatoes and that the effects were more pronounced as the dosage levels increased. The latter observation concurs with the findings of Salunkhe et al. (91). According to Panalakas and Pellefier (72) levels of gamma radiation did not cause consistent variation in ascorbic acid content of potatoes. Mickaelsen and Roer (63) reported that vitamin C content was decreased in both irradiated and non-irradiated potatoes during the first seven months of storage at 40° F but was restored after this period, and that ascorbic acid levels of the radiated samples were higher than those of the control.

Kung et al. (52) reported that vitamin A and C and tocopherols were sensitive to gamma radiation at sterilization doses. Vitamin analysis for thiamine, riboflavin, carotene, and pyridoxine indicated that the amounts of these vitamins destroyed by the sterlizing dose of cathode rays and X-rays were not as drastic as ascorbic acid. However, they were comparable to the amounts destroyed by the conventional method of thermal processing (34, 35, 54).

In short, the low doses of radiations have promising application in extending the storage life of fresh fruits and vegetables. Doses below 10 to 15 $\times$ 10^3 rads can reduce sprouting losses; below 1 $\times$ 10^5 rads can inhibit insect infestations; and below 2 to 3 $\times$ 10^5 rads can effectively curb mold growth without much loss in quality and in nutritive value of many fruits and vegetables.

METHODS AND MATERIALS

Fruits and vegetables for the experiments were obtained through a local wholesale dealer and from the Field Stations of the Utah State Agricultural Experiment Station. Only top-quality produce was selected. After selection, some of the fruits and vegetables were treated with chemicals in order to study the effects of chemicals plus irradiation in inhibiting mold growth. They were then placed in sealed or perforated No. 10 tin cans containing No. 10 Kraft paper bags or other liners. Cardboard dividers were used in the cans to prevent bruising of the samples during travel. The cans were labeled for dose, rate, temperature of radiation, and for varieties. The products were sealed and placed in a traveling refrigeration unit with a constant temperature of 40° F and were transported to the National Reactor Testing Station near Arco, Idaho, or to the Dugway Proving Ground, Dugway, Utah. The cans containing fruits and vegetables were irradiated with gamma rays from spent fuel elements at both facilities. Radiation temperature studies were conducted at the Dugway facility. The descriptions and methodology of irradiation at each of the facilities are presented below:

National Reactor Testing Station, Near Arco, Idaho

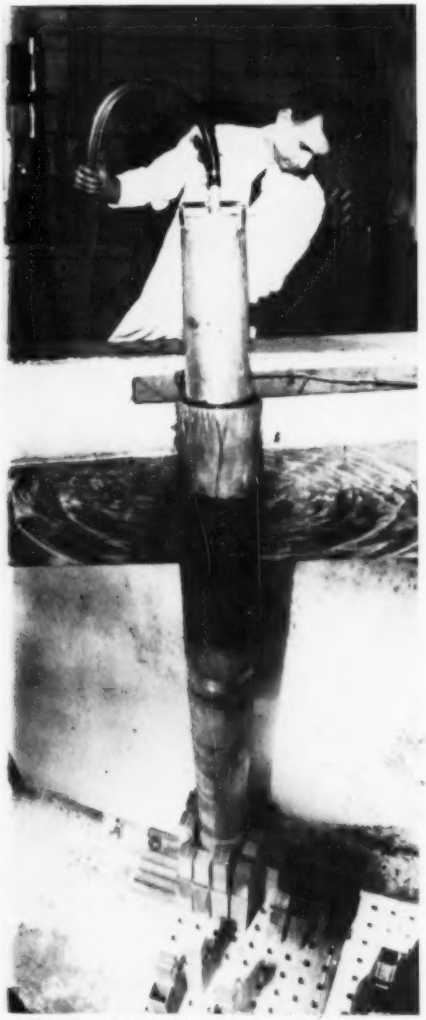
This facility uses as its fuel source spent fuel rods from the Material Testing Reactor. The spent rods are discharged into a water-filled canal approximately 25 feet deep. The rods, 6 x 6 x 24 inches in size, are moved into frames. In order to stop the gamma rays which are emitted from the spent fuel rods, these frames remain under 18 feet of water.

In the canal in which the frames of spent rods are placed, there is a 20 foot vertical aluminum pipe. This pipe is weighted with lead and sealed at the bottom. It has been referred to as the U.I.A.[6] column. For irradiation, cans containing foods were lowered into this column in a container known as an aeration chamber (Figures 3 and 4). This chamber is constructed from a 2 foot section of 7 inch diameter aluminum irrigation pipe. One end is welded shut with an aluminum bottom and weighted with 35 pounds of lead. The top consists of an aluminum lid made tight by a rubber gasket. Into this lid is fastened, by means of a gasket, a 6 inch piece of ¾ inch iron pipe. To this piece of pipe is clamped a 25 foot length of ½ inch (outer diameter) Tygon tubing. When two perforated No. 10 cans are placed in the aeration chamber, air could be forced at 10 pounds pressure per square inch into the cans. To accomplish this, within the chamber the air is divided with a glass Y and taken by auxiliary tubing to each perforated can. The exhaust air escapes from the chamber through the space between the small tube and the wall of the large tube.

[6]Named after the University of Idaho at Aberdeen, Idaho.

For irradiation, two No. 10 cans of food were placed in the aeration chamber. This chamber was then lowered to the bottom of the water column and allowed to remain for a calculated length of time. Irradiation took place under air circulations of 10 p.s.i. pressure.

Dosimeter measurements were used to calculate the dose (amount of radiation) and rate (distance from the source of the radiation). After the dose and rate were calculated, they were controlled by the distance between the cans and the fuel elements and the length of time the cans



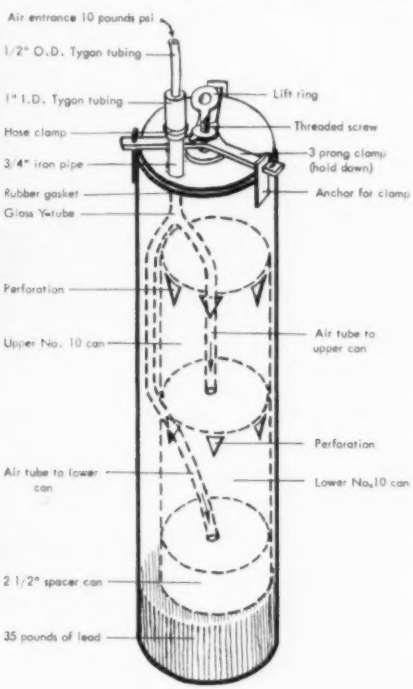


Fig. 3., (Left) The aeration chamber used during the process of radiation under water at Arco, Idaho, facility, constructed by R. K. Gerber and E. Devine.

Fig. 4. (Right) Cutway section of the aeration chamber.

remained exposed to the gamma rays. To insure equal dosage for both cans in the aeration chamber, at the end of half the allotted radiation time the chamber was brought to the surface and the position of the top and bottom cans interchanged.

After irradiation, each can of food was inspected by health officials for the emission of radiation. In any case of suspected contamination the product was kept at the center for further study. None of the products used in this study was thus retained.

Dugway Proving Ground, Dugway, Utah

The irradiation arrangement at Dugway, Utah differed considerably from that at the National Reactor Testing Station. Irradiation at this facility is accomplished under the protection of lead, concrete, and glass windows. Glass windows are arranged to act as tanks containing a zinc bromide solution.

Where irradiation takes place, there is a circular revolving tube which receives No. 10 cans containing food samples. Around the tube is arranged a water jacket that can be cooled or heated as necessary during irradiation. Fuel elements are placed around this water jacket with one foot of lead encasing the entire apparatus. The tube is open at each end so that it not only receives, but also ejects the containers. Radioactive emanations were not blocked at the open ends; therefore, the necessity of further protection as described above is obvious. The entire setup is mechanical and can be operated electrically. A push rod, set in motion according to the desired dose by a timed cam, pushes the series of cans through the revolving tube (Figure 5). When irradiation was completed, the same post-irradiation procedures as described earlier were followed.

Following radiation, the cans were returned to the research laboratories of the Department of Horticulture. Subse-

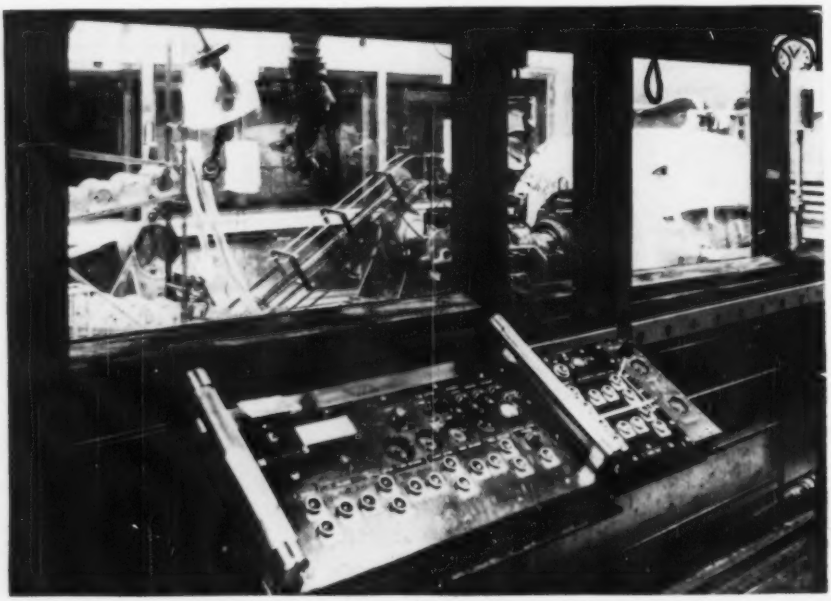


Fig. 5. Gamma radiation facility at Dugway Proving Ground, Dugway, Utah.

quently, they were stored at 40°, 50°, or 70° F until opened for organoleptic appraisal and microbiological studies at specified intervals.

The microbiological study consisted of an evaluation of the type and degree of mold growth found on the non-irradiated and irradiated fruits. Upon opening the cans, visual examination was made of the amount of mold growth on the prod-

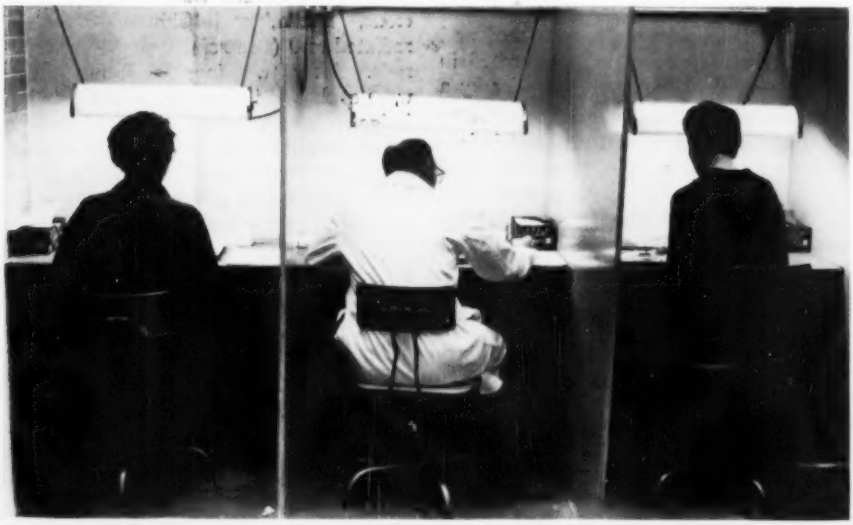


Fig. 6. (Above) Quality evaluation room.
Fig. 7. (Below) Arrangement of samples to be evaluated and scored.

uct. Subsequently, streak plates were made using Czapek's nutrient agar as a culture medium. Afterwards, the cultures were stored at room temperature for three or four days; then the molds were isolated and classified.

Taste preference of the irradiated and non-irradiated products was evaluated in the Food and Nutrition laboratories by a trained panel of 10 judges.

After microbiological study and before sensory judging, samples were examined carefully to determine color, texture, odor, and other physical characteristics. Then after selecting a uniform number of respective samples, these were washed and served either raw or cooked for judging in coded standard wax cups. Irradiated and non-irradiated samples of the same variety were put on a tray and placed in a darkened judging room. The large judging table was divided into five partitions. Each partition was equipped with a red light in order to keep sample colors as nearly alike visually as possible (Figures 6 and 7).

Because of its flexibility, simplicity, and reliability of results, the Hedonic scale suggested by Peryam and Pilgrim (74) was used for scoring. This scale has nine phrases arranged from 1.0 (dislike extremely) to 9.0 (like extremely). Judges were instructed to taste each sample and to encircle the phrase which best described their feelings about the sample. Crackers and/or water were available for rinsing the mouth between samples. After the judging was completed, taste preference scores for each sample were added together and divided by the number of judges. This gave the final average score.

In percent survival, the product was removed from the cans, total and non-moldy fruits or vegetables were counted, and the percentage of non-moldy edible product was calculated. The adjusted taste preference scores were then obtained by multiplying the taste preference scores by the per cent survival.

EXPERIMENTAL PROCEDURES AND RESULTS

Radiation Dose Effects

Apricots. Five varieties of apricots—'Perfection,' 'Hungarian,' 'Wilson Delicious,' 'Stella,' and 'Chinese'—were irradiated to 0 (control), 1, 3, and 5×10^5 rads. After two days of storage, they were evaluated for quality by the panel of judges. All varieties seemed to become slightly softer as the radiation dosage increased. 'Perfection,' 'Hungarian,' and 'Wilson Delicious' developed brown spots on the skin when treated with the higher dosage of radiation. The scores, however, indicated that all varieties at all doses were "like moderately" to "very much" by the judges.

The apricots were again sampled after eight days' storage at 50° F. As the radiation dose increased, the fruits exhibited brown spots, bruising and softening. However, the judges still liked the taste "moderately" to "very much." Most varieties developed mold at the control and at the 1×10^5 rads level. In general, Chinese variety of apricots appeared to be the best for radiation preservation.

Black Raspberries. Samples of black raspberries were irradiated to 0 (control), 1, 2, 3, and 4×10^5 rads. They were evaluated by the taste panel 4 and 11 days after radiation. The non-irradiated fruits were "liked moderately" by the judges. There seemed to be no consistent change in taste scores of the irradiated fruit at this range of irradiation at the fourth-day period nor with the edible fruits at the eleventh-day interval. At the latter period, however, there was mold on some of the control 1, and 2×10^5 rads samples. On the other hand, it was noted that irradiation at the 3 and 4×10^5 rads increased the refrigeration life of black raspberries.

Grapes. Thompson seedless grapes were obtained from a local wholesale dealer and were irradiated to 0 (control), 1, 2, 3, 4, and 5×10^5 rads. Subsequent to

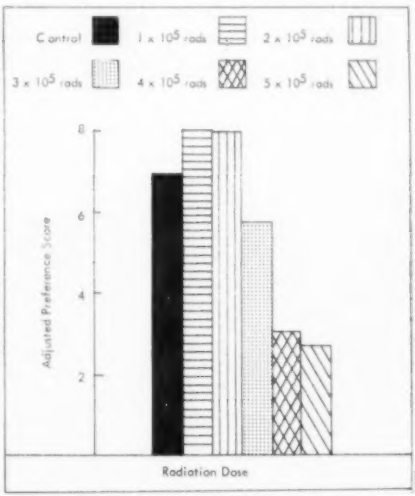
irradiation, the grapes were stored at 40° F for one month. The adjusted preference scores were calculated from mold and color points of view. Figure 8 indicates that fruits irradiated to 1 and 2 $\times$ 10^5 rads doses were well liked and marketable. Fruits irradiated to 3, 4, and 5 $\times$ 10^5 rads were unmarketable because they developed deep brown color. This may have been due to the activation of certain enzyme systems by higher doses of radiation to produce browning in the fruit. However, there was no mold and no off-flavor. A replication of all the treatments was tasted after three months, and similar results were noticed. The controls were inedible due to profuse mold growth.

Pears. Bartlett pears, yellow ripe, and mature green, were irradiated to 0 (control), 0.25, 1, 2, 2.5, 3, 4, 5, and 7.5 $\times$ 10^5 rads. Subsequent to irradiation and prior to taste evaluation, they were stored at 40° and 70° F for five and seven days, respectively. It was found that there was no difference in the taste preference of ripe pears which received 0.25 and 1.0 $\times$ 10^5 rads. There was a progressive degradation in the taste preference and increased browning of the irradiated ripe pears as the radiation advanced beyond these doses. However, such degradation was not as pronounced in the case of irradiated green pears. High taste preference scores were extended to 2.5 $\times$ 10^5 rads dose. The development of the browning was delayed when such irradiated pears were sprayed with 0.1 per cent ascorbic acid solution.

Tomatoes. Tomatoes were obtained from a local wholesale dealer for these experiments. Tomatoes selected were of the following visual maturities: 1. grass green, 2. pink with yellowish tinge, 3. red ripe.

These tomatoes were irradiated to 0 (control), 0.5, 1, 3, and 5 $\times$ 10^5 rads. Following radiation, the tomatoes were stored at 50° and 70° F temperatures to study the color and mold growth. Some of the pink and ripe tomatoes were evaluated for quality immediately after radiation, and some after 14 days' storage at 70° F. It was noticed that the quality of tomatoes declined as the radiation dose advanced over 1 $\times$ 10^5 rads. It was also noticed that the quality of the tomatoes irradiated in the pink stage did not deteriorate as rapidly as that of irradiated ripe tomatoes after 14 days' storage. In general, it was apparent that the red color development and maturation were retarded between the dose of 1 and of 3 $\times$ 10^5 rads. The mold population was reduced progressively as the radiation dose advanced over 1 $\times$ 10^5 rads. Green tomatoes irradiated over 1 $\times$ 10^5 rads did not ripen evenly and did not develop red color.

Yellow Sweet Corn. Four varieties of yellow sweet corn—'F. M. Cross,' 'Golden Cross Bantam,' 'Seneca Chief,' and 'Victory Golden'—were included in



THOMPSON SEEDLESS

Fig. 8. Effect of radiation dose on the adjusted taste preference score for Thompson Seedless Grapes stored at 40° F. and after one month, evaluated.

this experiment. The ears were harvested when the crop was of prime maturity and quality. Ears with husks were then irradiated to 0 (control), 2, 3, and 5×10^5 rads. Perforated cans containing the corn were stored at 40° F for 6 and 16 days before evaluation.

The quality evaluation indicated that there was insignificant change in the taste preference scores with increase in radiation dose at the 6-day storage period but that there was a decrease in the taste preference scores with increase in dose at the 16-day storage period. 'F. M. Cross' and 'Golden Cross Bantam' maintained better quality than did 'Seneca Chief' and 'Victory Golden' with the the higher dose at the 16-day interval. Slight mold growth was seen on the husks at control and 2×10^5 rads. Nevertheless, the moldy husks were removed, and the corn was cooked and served. No mold was present on husks of the corn irradiated at 3 and 5×10^5 rads.

Peas. Samples of 'Perfection' peas in the pods were selected as overmature (size numbers 5 and 6 on the canner's grade) to determine the value of irradiation in softening up these peas and in changing the taste scores. The peas were irradiated to 0 (control), 1, 3, and 5×10^5 rads and were evaluated 4 and 11 days after irradiation.

The control peas at 4 and 11 days were judged a little better than "like slightly" by the panel. There was a slight decrease in taste scores as the dosage of radiation increased.

The pods of the peas stored 11 days differed as a result of the irradiation. Those at control and 1×10^5 rads were brown and moldy. Those at 3 and 5×10^5 rads were green and not moldy.

Shear-press values (48) and a sugar analysis of the samples of peas after 11 days of storage subsequent to irradiation indicated that peas became softer and sweeter as the dose of radiation increased.

Asparagus. *Experiment 1.* Asparagus spears of uniform size and maturity were irradiated to 0 (control), 1, 3, and 5×10^5 rads. Subsequent to radiation, the cans were opened to study the tenderness. It was noticed that the asparagus irradiated at 5×10^5 became soft immediately after radiation. However, the asparagus irradiated at lower doses became slightly softer upon storage at 40° F for six days. One explanation may be that at higher doses of radiation the organic compounds of pectin, cellulose, and lignin may be degraded during the process to cause softening. The lower doses of radiation might accelerate the action of enzymes to produce the softening within a few days.

Experiment 2. For this experiment, asparagus was blanched in boiling water for three minutes to inactivate enzyme systems and then sealed in polymylar bags. These samples were irradiated to 0 (control), 1, 3, and 5×10^5 rads. Subsequent to radiation, these bags were stored at 50° F.

Gas developed in bags containing the non-irradiated and the irradiated (1×10^5 rads) asparagus, whereas no gas developed in bags which were irradiated to 3 and 5×10^5 rads. The non-irradiated asparagus and that which received 1×10^5 rads became moldy and unfit for human consumption after 12 days, whereas the asparagus which was irradiated at 3 and 5×10^5 rads retained its green color and quality for 30 days.

Experiment 3. Asparagus for this experiment was divided into three grades. These grades were as follows:

Grade I: The apex of asparagus spear —the first apical cut which is tender and preferred by the consumer.

Grade II: The second cut—green cut, which is sometimes discarded.

Grade III: The third cut—white, overmature, always discarded because it is too old for consumption.

The uniformity of these grades was checked with the pressure tester method of Kramer et al. (49). These samples were

irradiated to 0 (control), 0.5, 1, 3, and 5×10^5 rads. The asparagus was evaluated organoleptically 2 days, 14 days, and 30 days after radiation. Also, shear-press readings were taken on certain samples.

It was found that the quality of irradiated asparagus did not change significantly in the dose levels studied at 2 and 14 days. However, in general, the quality of the irradiated (at low doses) asparagus was satisfactory after 14 days' storage at 40° F, and the quality was lowered in all doses when evaluated after 30 days' storage.

It was further found that as the dose of radiation advanced, the tenderness of the second grade asparagus increased. Such second grade asparagus heretofore discarded may very well be used in the frozen food industry.

Strawberries. *Experiment 1.* For this experiment six varieties of strawberries—'Kasuga,' 'Lindalicious,' 'Marshall,' 'Robinson,' 'Shasta,' and 'Sparkle'—were obtained from the Howell Field Station, Ogden, Utah, and were irradiated to 0 (control), 1, 2, and 3×10^5 rads. 'Kasuga' and 'Lindalicious' were at the stage of excellent commercial ripeness; 'Marshall,' 'Robinson,' and 'Shasta' were in a fair-to-good commercial ripeness, slightly on the overripe side; while the variety 'Sparkle' was slightly dry as a result of inadequate irrigation before harvest. The samples of strawberries were stored at 40° F and were evaluated for mold growth and taste quality every fifth day starting on the third day after irradiation and continuing for 25 days.

All six varieties of strawberries showed an increase in refrigeration life with increases in radiation, but the organoleptic quality of the strawberries declined progressively as the storage period was extended (Figure 9).

In general, throughout the experiment, a peculiar spongy-soft texture was observed in all varieties at 3×10^5 rads. As the storage period was lengthened, the number of spongy berries became more apparent. With the exception of 'Kasuga' and 'Sparkle,' all varieties exhibited varying degrees of bleaching at 2 and 3×10^5 rads throughout the experiment. The physical quality of irradiated 'Kasuga,' 'Lindalicious,' and 'Sparkle' strawberries did not decline as fast as that of 'Marshall,' 'Robinson,' and 'Shasta.' Hence, it is apparent that 'Kasuga,' 'Lindalicious,' and 'Sparkle' varieties have better keeping quality than the others.

Of the types of mold causing rot in strawberries, *Hormodendrum* was the most common. It appeared in about 60% of the cans and was observed in all doses. Although *Botrytis* was found only in 25% of the cans, the author feels that where it was present it caused more spoilage than did any other type of mold, because of its profuse growth habit. *Penicillium* appeared only in the control fruits, indicating that radiation inhibited *Penicillium*. Other types of mold—*Alternaria*, *Aspergillus*, *Rhizopus*, and *Stemphylium*—found growing on the fruits were of minor importance, since they were rather erratic in occurrence.

Experiment 2. This experiment was conducted to determine if partially green strawberries would be more suitable for irradiation than ripe strawberries.

'Shasta' strawberries were picked when they were at the green-tip stage. They were irradiated to 0 (control), 1, 2, and 3×10^5 rads and stored at 40° F until examined.

After 15 days' storage at 40° F and 2 days at room temperature (for ripening purposes), berries were judged. Adjusted taste preference scores were then calculated. From the information obtained, it was concluded that the berries were unacceptable in taste quality. Adjusted taste preference scores varied from 1.3 (dislike extremely) to 3.4 (dislike moderately). These low scores were indicative of a lack

of flavor development. However, adjusted preference improved in varying degrees following irradiation, due to the inhibition of mold growth. There was wide variation in color. Control ranged from medium dark red to yellow red. Some brown spoiled spots were present. As dosage increased, berries became more immature and underripe.

Microbial observations indicated that after 15 days' storage there was little mold growth. At the end of 49 days, all of the fruit in control and 1×10^5 rads was moldy, while at 2 and 3×10^5 rads less mold appeared. *Alternaria, Botrytis, Hormodendrum, Stemphylium,* and *Penicillium* were present throughout, with *Botrytis* and *Hormodendrum* being the most prevalent.

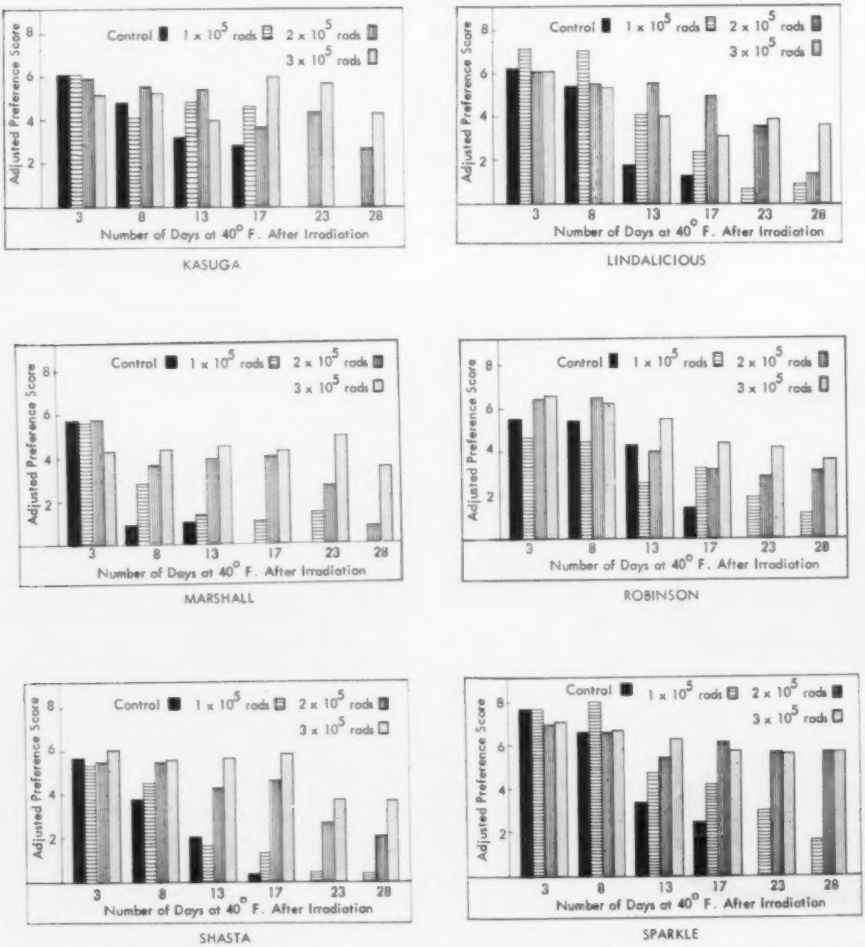


Fig. 9. Effect of radiation dose on the adjusted preference score for 'Kasuga,' 'Lindalicious,' 'Marshall,' 'Robinson,' 'Shasta,' and 'Sparkle' strawberries stored at 40° F. and evaluated after 3, 8, 13, 17, 23, and 28 days.

Sweet Cherries. Four varieties of sweet cherries—'Bing,' 'Lambert,' 'Napoleon,' and 'Windsor'—at the firm-ripe stage of maturity were irradiated to 0 (control), 2, 3, and 4 $\times$ 10^5 rads. The samples of cherries were then stored at 40° F and were evaluated for mold growth and taste quality every seventh day, starting 8 days after irradiation and continuing for 63 days.

Generally speaking, fruits of all varieties showed an increase in refrigeration life with increase in radiation. Adjusted taste preference scores increased with increased radiation. As the storage period increased, non-irradiated cherries became progressively riper, but those irradiated at 2, 3, and 4 $\times$ 10^5 rads levels exhibited less ripening (Figure 10). From Figure 11 it will be noted that the adjusted taste preference scores for these varieties declined progressively as the storage period advanced, regardless of radiation dose. 'Bing' seemed to be the best all around cherry for radiation preservation.

Alternaria and *Hormodendrum* were the two most common types of mold causing rot in sweet cherries. Both were present in about 80% of the samples. About 70% of the control fruit was infected by *Penicillium*, but this mold was not observed in any of those irradiated samples. *Stemphylium* was present in about one-third of the treatments, and *Botrytis* was noticed in samples when irradiated at 3 and 4 $\times$ 10^5 rads.

Bulb, Tuber, and Root Crops. Annually, hundreds of thousands of dollars are spent to store bulb, tuber, and root crops under refrigeration in order to preserve them from sprouting and shriveling. An attempt, therefore, was made to investigate the possibilities of using gamma radiation to minimize sprouting losses of these crops.

The cans containing carrots, turnips, beets, and parsnip roots, onion bulbs, and potato tubers were irradiated at 0 (con-

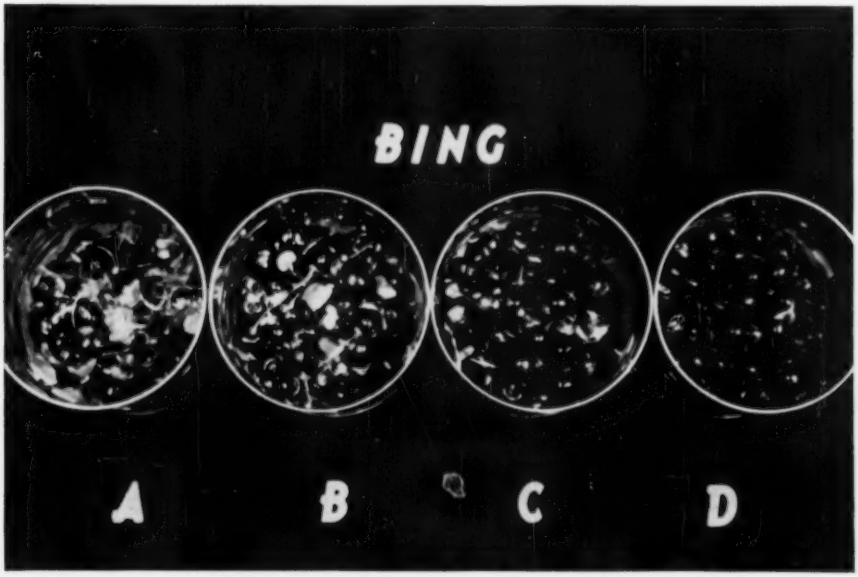


Fig. 10. The effect of radiation dose on mold growth and maturation of 'Bing' cherries. Left to right: A = Control; B = 2 $\times$ 10^5 rads; C = 3 $\times$ 10^5 rads; and D = 4 $\times$ 10^5 rads.

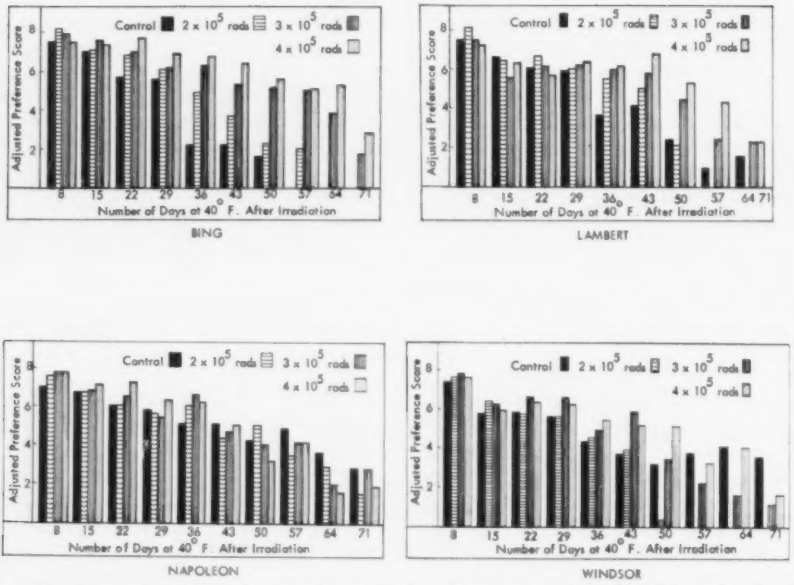


Fig. 11. Effect of radiation dose on the adjusted preference score for "Bing," "Lambert," "Napoleon," and "Windsor" cherries stored at 40° F. and evaluated after 8, 15, 22, 29, 36, 43, 50, 57, 64, and 71 days.

trol), 1.9, 3.7, 7.4, 9.3, 14.9, 29.8, 59.5 $\times$ 10^3 rads. Following irradiation, the cans were opened and stored for five months at 50° F and at 85 per cent relative humidity.

At the end of the storage duration it was found that at the high doses (over 14.9 $\times$ 10^3 rads) of radiation the sprouting was either retarded or inhibited. However, a slight acceleration of sprouting was noticed at the 3.7 $\times$ 10^3 rads dose.

In general, radiation doses 9.3 $\times$ 10^3 rads for potatoes (Figure 12) and beets; and 18.6 $\times$ 10^3 rads for carrots (Figure 13), onions, turnips, and parsnips inhibited sprouting for practical purposes. Doses higher than these did not result in additional significant decreases of sprouting. The dose of radiation did not change sensory quality of these crops during the first month of storage. However, subsequent to storage for four months at 50° F and 85% relative humidity, the quality scores increased as the dose of radiation increased, which may be due to the reduction in sprouting losses. In addition, the greening of irradiated potatoes (over 9.3 $\times$ 10^3 rads) was inhibited.

Radiation Dose and Rate Effects

Cabbage and Cauliflower. Cabbage and cauliflower heads of medium size were irradiated to the doses of 0 (control), 1, 3, and 5 $\times$ 10^5 at the rates of 1 $\times$ 10^6 rads and 3 $\times$ 10^6 rads/hour. The irradiated products were evaluated for quality within 48 hours after radiation as well as after 10 days' storage at 40° F after radiation.

No significant effect of radiation rate on the quality of cabbage or of cauliflower was evident, regardless of the storage period. The overall readings showed that the cabbage and cauliflower irradiated at the low (1 $\times$ 10^6 rads) rate was slightly better than the irradiated at high (3 $\times$ 10^6 rads) rate. The quality declined when

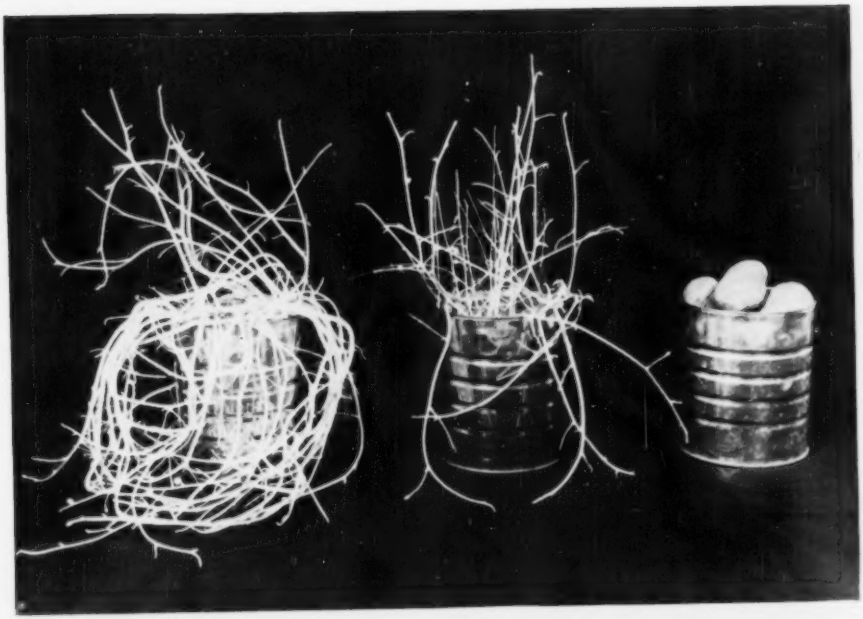


Fig. 12. (Upper) Effect of radiation dose on the sprout inhibition of potatoes stored for five months at 50° F. Left to right—non-irradiated; 4.65×10^5 rads; and 9.30×10^5 rads.

Fig. 13. (Lower) Effect of radiation dose on the sprout inhibition of carrots stored for four months at 50° F. Left—non-irradiated; right—irradiated at 18.6×10^5 rads.

irradiated over 3×10^5 rads dose in both radiation rates.

Apricots. For this experiment, two varieties of apricots, 'Chinese' and 'Moorpark,' were irradiated to 0 (control), 2, 3, and 4×10^5 rads at the slow rate of 1.26×10^6 rads/hour and duplicate samples at the fast rate of 8.08×10^6 rads/hour. Both varieties were firm-ripe, but 'Moorpark' was on the green side, because this variety becomes very soft upon ripening. The samples of apricots were stored at 40° F and were evaluated for mold growth and taste quality every seventh day, starting 7 days after irradiation and continuing for 42 days.

The refrigeration life of the irradiated fruits was increased in these two varieties to a limited extent as compared to the non-irradiated fruits, especially those irradiated at 2 and 3×10^5 rads levels. The storage life of apricots irradiated at 4×10^5 rads level was decreased, regardless of radiation rate. This loss in storage life was due to the breakdown of tissue which resulted in large, brown, and bruised-like areas on the fruit. The adjusted taste preference scores for both varieties declined progressively as the storage period advanced, regardless of the radiation dose and rate. In general, adjusted preference scores increased with increased radiation. It seems that the optimum radiation dose for extending the storage life without losing the quality of apricots would be about 2×10^5 rads. The two different rates of radiation did not reveal any appreciable significance in the amount of mold growth on apricots (Figures 14 and 15). There was considerable mold growth on fruits irradiated at the high dose (4×10^5 rads) (Figures 14 and 15), because radiation made the fruit very soft and vulnerable to penetration of mold organisms.

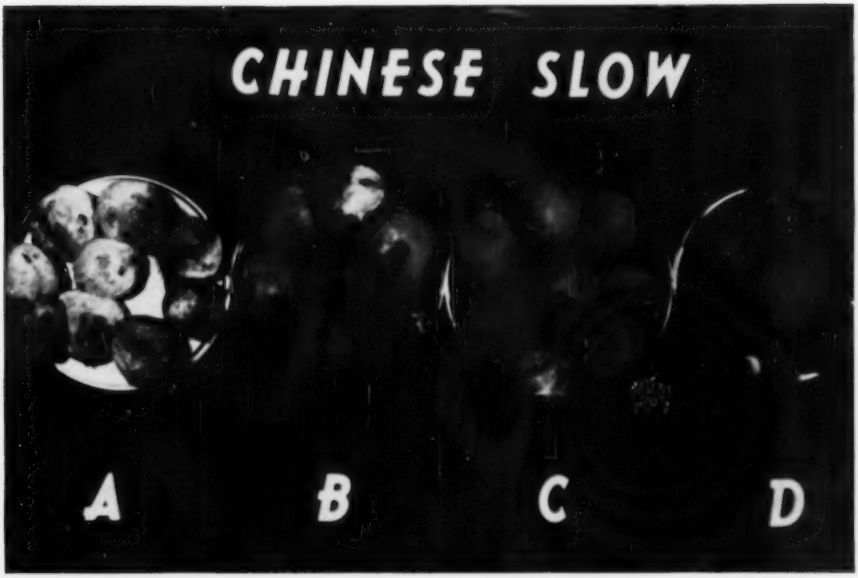
Four types of mold—*Alternaria*, *Penicillium*, *Hormodendrum*, and *Stemphylium*—were common in this experiment. Most common was *Hormodendrum*, which occurred in about 50% of the samples. *Alternaria* and *Stemphylium* were present in about 35 and 20%, respectively. *Penicillium* appeared in about 25% of the control samples, but none was observed in the apricots which had been irradiated.

Radiation Temperature Effects

Apricots. Firm-ripe fruit of the Chinese ('Large Early Montgamet') variety was irradiated to 0 (control), 1, 3, and 5×10^5 rads and at temperatures of 40°, 70°, 100°, and 130° F. After returning the samples to Logan, a replicate of each of the radiation dose levels and of the radiation temperature treatments was evaluated for taste preference. The remaining samples were stored at 40° F for 10 and 24-day intervals; moldy fruits were removed before tasting. The per cent survival (non-moldy fruits) was calculated. It was found that at the control and 1×10^5 rads levels the adjusted preference scores decreased with increase in storage duration and also with increased radiation temperature. However, 3 and 5×10^5 rads scores increased moderately from 1 to 10-day storage period and slightly from 1 to 24-day interval. As storage duration and radiation temperature increased, the samples became rather shriveled. In general, the actual taste preference of non-moldy fruit was unaltered by the radiation dose. However, the adjusted taste preference scores indicated that the quality scores were progressively higher as the radiation dose advanced, because radiation inhibited mold growth.

Sour Cherries. Firm-ripe fruit of the variety 'Suda' was obtained from the Howell Field Station and irradiated to 0 (control), 1, 3, and 5×10^5 rads at 40°, 70°, 100°, and 130° F. It was then stored at 40° F for seven weeks.

At the end of seven weeks, some of the sour cherries were sorted and evaluated raw; other samples after sorting were cooked in 40% sugar solution be-



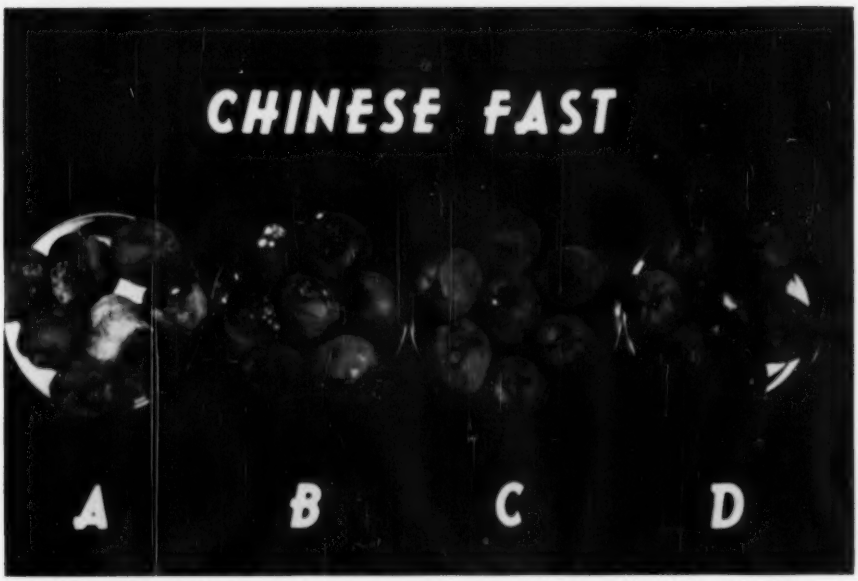


Fig. 14. (Upper) Effect of radiation dose and slow rate (1.26×10^6 rads/hour) on the mold growth on 'Chinese' apricots.

Fig. 15. (Lower) Effect of radiation dose and fast rate (8.08×10^6 rads/hour) on the mold growth on 'Chinese' apricots.

fore evaluation. The preference scores of the tasted fruit decreased with increase in radiation dose and showed no consistent change with increase in radiation temperature. The adjusted preference scores increased with advanced radiation dose, indicating the progressive inhibition of mold as the dose levels became larger.

The juice of fruit at the higher (3×10^5 rads) doses of radiation was clearer and lighter red than was the juice of the cherries at the lower (1×10^5 rads) dose. This was confirmed by the colorimeter readings, which showed progressive degradation of red pigment at higher ($3^5 \times 10^5$ rads) doses of radiation.

Peaches. Firm-ripe fruit of variety Prairie Sunrise was irradiated to 0 (control), 1, 3, and 5×10^5 rads at 40°, 70°, 100°, and 130° F. It was then stored at 40° F. A replicate of each radiation dose and radiation temperature was evaluated for taste preference after 1 and 10 days' storage.

It was evident that the taste preference scores after 10 days' storage were slightly higher than at 1-day storage. This was probably due to riper fruit. However, after 10 days of storage, there was a substantial increase in the adjusted preference scores at the 3×10^5 rads level. This was due to progressive reduction in mold growth as the radiation dose increased. The decrease in score at the 5×10^5 rads level could be due to loss of flavor from the high dosage. There seemed to be no consistent trend of adjusted preference scores with increase in radiation dose and temperature.

Broccoli. Broccoli was obtained from a local produce dealer and irradiated to 0 (control), 2, 3, and 4×10^5 rads at 40°, 80°, and 120° F. The samples were stored at 40° F for 14 days. Subsequent to storage they were evaluated for taste preference. It was found that there was a slight decrease in preference scores with increase in radiation dose. However, it was not significant. Likewise, no significant effect of radiation temperature was evidenced. Due to irradiation, many of the buds (sprouts) did not open and were in good condition.

Packaging and Radiation Effects

Strawberries. For this experiment 'Shasta' strawberries were treated with 1% concentrations of either Captan or sorbic acid before irradiation at 0 (control), 1, 2, and 3×10^5 rads. The purpose of this experiment was to determine if a combination treatment of irradiation with a fungus-inhibiting chemical would prove more effective than irradiation alone. Fruits treated with Captan showed less microbial growth and had a higher percent survival than those treated with sorbic acid.

Hormodendrum was not present in the fruit treated with Captan; therefore, it appears that Captan inhibits the growth of this mold. *Botrytis* was prevalent throughout the experiment. Occasionally, *Penicillium* and *Stemhylium* occurred.

Sweet Cherries. In this experiment, 0.1% concentration of five different fungus-inhibiting chemicals—Captan, D.H. A.-S, Dowicide A. Mycostatin, and potassium sorbate—were used in conjunction with radiation to 0 (control), 2, 3, and 4×10^5 rads. Two varieties of cherries, 'Bing' and 'Lambert,' were used. The fruits were dipped in the chemical solutions prior to irradiation. After dipping, the cherries were dried and placed in two types of packaging bags. 'Bing' and 'Lambert' cherries were placed in polyethylene (0.0015 inch thick) and in 50 Mylar C bags, previous to sealing in No. 10 tin cans for radiation.

In comparison with berries treated by radiation alone, the cherries in this experiment have shown a greater degree of survival for a longer storage period. Fruits irradiated at higher doses (3 and 4×10^5 rads) had less mold than did those of the lower dose (2×10^5 rads) of radiation. The percent survival was considerably less for cherries stored in

polyethylene bags than for those in 50 Mylar C bags. It was noticed that there was more condensation in the polyethylene bags than in the 50 Mylar C bags. Cherries in polyethylene bags emitted a sour, disagreeable odor, had turned a brown color, and were not as firm as those in the 50 Mylar C bags. The fruit in the 50 Mylar C bags retained its natural color and firmness.

Four types of mold—*Alternaria, Penicillium, Hormodendrum,* and *Stemphylium*—were present in this experiment. However, as was found in the experiment with radiation alone, *Penicillium* grew only in the control treatments. Hence, it confirms the observations from earlier experiments that the growth of *Penicillum* mold is inhibited even by low doses of gamma radiation.

Snap Beans. 'Blue Lake' green beans of excellent canning quality were obtained from a local grower. The beans were placed in 12 different types of can liners—polyethylene (0.0015 inch thick), duPont No. 322, Mylar polyester film type C (0.0005 inch thick), cellophane 450 MSAD-84, Mylar 0.001 inch thick coated with 0.002 inch polyethylene, cellophane 450 MSD (Ful-Lok), cellophane 450 K-202, Saran Dow Code No. 120, parchment (27 pound weight), parchment (32 pound weight), polyethylene (0.10015 inch thick) perforated, and Kraft paper bag—and then sealed in perforated No. 10 cans. The samples were irradiated to 0 (control), 2, 3, and 5×10^5 rads at the Arco, Idaho, facility. The beans were stored at 40° F for 7 and 17 days, at which times they were evaluated for taste preference after cooking. It was noted at the seventh day evaluation that the taste preference scores decreased as the dose increased. A greater decrease occurred with increase in dose at the 17-day period. The non-irradiated controls were given almost the same scores at the end of 17 days as at 7 days.

It was noted that those beans in duPont Film No. 322 were given low scores at both time-test intervals. Beans in Kraft paper, parchments, and cellophane 450 MSAD 84 decreased most in score during the 10-day period between tests. Beans in polyethylene bags increased slightly in score during the 10 days. Cellophane 450 MSAD 84 and Mylar C gave excellent results for the first 7-day period. The latter material was still second choice at the end of the 17-day period. Beans stored in the parchments developed a toughness at the higher radiation doses (3 and 4×10^5 rads) which became rather noticeable at the 17-day storage period. Beans stored in all of the can liners decreased in crispness with increase in radiation dosage. After 17 days of storage, beans in most can liners were darker green in varying degrees. They were thought of as "damp" and regarded as "slimy." Beans in control cans with no liner were extensively covered with mold.

Tomatoes. Ripe tomatoes of prime quality were used for this study. Activated charcoal was placed in Kleenex tissue paper, making a package comparable to a tea bag. The package was sealed in No. 10 cans along with tomatoes, with some cans without such bags. These cans were irradiated to 0 (control), 1, 2, and 4×10^5 rads. The cans were stored at 70° F and opened 5 days after radiation and evaluated for quality. The quality of the irradiated tomatoes with charcoal was somewhat better than it was without charcoal. The activated charcoal may have absorbed the volatile substances and other harmful gases given out. A package of the activated charcoal may be included in cans during the process of radiation; and immediately after the radiation, such cans may be opened to permit normal metabolism of the product, provided the product is packaged in a semi-permeable film which will permit normal respiration of the product and, at the same time, will prohibit the entry of microbes.

GENERAL DISCUSSION

Storage Life and Other Factors

Sufficient doses of gamma radiation can destroy or inhibit many types of microorganisms. The amount of radiation required for pasteurization and sterilization depends on the type and number of spoilage organisms present as well as on the type of food material being handled.

Even though gamma radiation may be able to control microbial growth and extend storage life, retain nutritional value, reduce cost of handling, and inhibit the maturing and sprouting processes, the irradiated product should be edible and marketable to the consumer. Hence, the effects of gamma radiation on the following quality attributes need to be considered.

Flavor. Some of the undesirable flavor changes in irradiated fruits and vegetables at high doses are possibly due to the destruction of volatile esters and alcohols which are characteristic of these products. Proteins and certain protein fractions probably are the most important source of radiation-induced off-flavors. Sulfur-containing amino acids appear to be the most radio-sensitive of the amino acids. Other objectionable flavors may also originate in the micro-constituents of foods, such as vitamins and pigments. These were found highly susceptible to, and easily degraded by gamma radiation.

It has also been thought that radiation might bring about a more rapid deterioration of food substances by rendering complex components more susceptible to hydrolysis by enzymes. This would be due to the fact that whenever enzymes are not inactivated and their reaction rates are accelerated, a more rapid breakdown of the food may result. This might also cause flavor changes.

It is possible to control undesirable off-flavor-producing changes to some degree. Flavor of products tested remain unchanged when the products are irradiated in the presence of flavor-absorbing material such as activated charcoal. Also, the aeration of fruits and vegetables during irradiation is essential to retain the natural flavor and to extend the storage life of fresh fruits and vegetables by supplying oxygen for the normal respiration process, and at the same time, by removing carbon dioxide and other gases given out as a result of respiration and of radiation.

Texture. Texture changes in fruit during maturation and storage have been associated with the degradation of complex carbohydrates. Because of the importance of pectins and cellulose to the cellular structure of the fruit or vegetable, it has been found that textural changes in fruits are directly attributable to radiation degradation of carbohydrates. Also, some of the fragments of these degradations are reductone-like products which form brown pigments, resulting in discoloration of the food.

Color. Red color development has been found to be inhibited by exposure to gamma radiations. This may be due to a reduction of lycopene content following irradiation. The anthocyanin pigments of fruits, such as strawberries and cherries are also easily degraded at high doses of gamma radiation, and carotenoids and chlorphyll appear to be among the more stable plant pigments. Color, flavor, texture, and odor of products remain unchanged when they are irradiated in the presence of a free radical acceptor.

Marketing. The important problem of selling the irradiated foods will be that of consumer education and they will need proper packaging and publicity.

SUMMARY AND CONCLUSIONS

Experiments were conducted from 1955 to 1959 on 22 fruits and vegetables to study the effects of gamma radiation dose, rate, and temperature during radiation, pre-irradiation chemical treatments, and packaging methods on the quality, chemical changes, and storage life of the crops

The results and observations can be summarized as follows:

Selection of variety and the maturity of crops play an important role in preservation of fruits and vegetables by gamma radiation. It has been found that certain varieties of strawberries, cherries, corn, and apricots were suitable for radiation and that others were not. This finding, however, relates to the firmness of the product; that is, the firmer crops or varieties were more suitable for radiation preservation than the softer ones. Crops such as cherries, pears, grapes, cabbage, and corn were more suitable than other crops studied. No doubt the storage life varied from a few days to several weeks. In the same vein, it could also be said that the maturity of the produce selected for radiation has much to do with extension of its refrigeration life. Immature or green products, when irradiated, did not ripen evenly. When some over-matured crops were irradiated, the product became soft and prone to fungal infestation. In general, firm-ripe maturity is ideal for radiation preservation, regardless of crops and varieties studied. The ripening processes of many crops were delayed by low doses (2 to 3×10^5 rads) of gamma radiation. Therefore, it seems feasible to irradiate firm-ripe fruits and vegetables and to ship them to distant markets, with a consequent reduction in handling and storage losses.

The radiation dose requirement for pasteurization depends upon the number and kinds of microbial growths present on a given product prior to irradiation. However, in general, without much loss in quality most of the fruits and vegetables can be irradiated to 2 to 3×10^5 rads to extend the storage life from two to six weeks at the refrigeration temperature. Likewise, for sprout inhibition, a dose in the vicinity of 10 to 20×10^3 rads is sufficient for most of the bulb, tuber, and root crops.

Increased respiration and increased softening are predominant effects of radiation, especially at higher dose levels. Respiration products, such as CO_2 and other volatile gases, such as ethylene, are given out faster during radiation, and if allowed to accumulate are harmful to the products themselves. This occurs because fruits and vegetables are living. The aeration device, therefore, was developed and constructed and is rather unique and useful for furnishing air for the normal respiration of the product, and at the same time, for removing CO_2 and other volatiles given out during radiation. Also, when an activated charcoal was included in the package to be irradiated, the off-flavor was diminished.

The radiation dose effects were determined on several components, such as vitamins, carbohydrates, proteins, and pigments of fruits and vegetables. In general, the degradation of the complex components of fruits and vegetables was noticed when these were irradiated at high (over 5×10^5 rads) doses.

Softening effects of radiation show some promising possibilities. Slightly older corn, asparagus, or peas could be irradiated; and the pericarp of corn, the fiber of asparagus, and the cellulose of peas could be "softened" and made more edible.

Radiation rates and radiation temperatures have not shown significant and consistent effects on the fruits and vegetables studied. However, it would be advisable to irradiate products at the fast rates to save time and to irradiate products at low temperatures to reduce shriveling of products.

Packaging and pre-packaging treatments do have some place in the radiation preservation of fruits and vegetables. Radiation alone will not inhibit or kill all microbial population present on samples. Hence, pre-irradiation chemical treatment, such as antibiotics and anti-fungal chemicals, is necessary. At the dose levels studied, it was found that *Penicillium* fungus is inhibited by radiation and that

Hormodendrum is not. However, pre-irradiation chemical treatment with Captan and DHA-S inhibits the growth of *Hormodendrum*. Several antibiotics and anti-fungal chemicals were included in the experiments. Some of them show some promise in combination treatment with radiation.

The selection of packaging film is an important factor; certain films disintegrate during radiation and impart their flavor to the products. Some films are rather stable and satisfactory for wrapping fruits and vegetables. Cherries stored in polyethylene bags disintegrate and are unacceptable after one month at 40° F, regardless of radiation dose. However, those irradiated in Mylar C bags are in excellent condition even up to two months when irradiated at 2×10^5 rads. In addition, the condensation of water vapor is maximum in polyethylene bags. Hence, relative humidity increases around the fruit and subsequently fosters a profuse mold growth, regardless of radiation doses. However, the fruits irradiated in Mylar C were in good condition; no water condensation was evidenced. Fruits thus packaged and irradiated can be stored in excellent condition for two months. I think that the success of radiation preservation will depend upon the availability of a film which is stable during radiation as well as permeable to CO_2, O_2, and other volatiles and, at the same time, impermeable to most microbes.

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Utilization Abstract

Beauty Salon, Tea Room, and Home-brewed "Teas," an abstract of studies on beverages. Currently, an extensive list of plant parts are found in "tea" beverages. Phytopharmacologic studies of effects of these beverages upon animal and human physiology has revealed a surprising number of botanical species being used for this purpose in the United States. Chemical analyses of plant parts employed present great diversification in organic compounds. Their effects on a variety of organs have been demonstrated experimentally and their influence upon the health of the consumer noted over short and long periods of time.

In addition to the dominant usage of pure China tea, many commercial teas contain ingredients derived from both domestic and imported botanical materials. Their origin involves all major taxonomic divisions except Bryophyta, and all typical parts of plant structure are utilized. Phytochemically, the compounds include sugars, aromatic oils, alkaloids, glucosides, tannins, coloring principles and a multiplicity of flavoring agents. Pharmacologically, they influence—as stimulants, depressants, temporary excitants, and as tranquilizers—the activity of the digestive system movements and secretions; the nervous system; the heart; skeletal and tubular musculature of the body; the breathing rate and oxygen consumption; the rate, composition, and volume of urine formation; and, in one instance, the fluorine content may be a factor aiding in protection of teeth against dental caries. In some preparations the dried flowers of *Papaver rhoes* L., the beautiful "Shirley" of gardens, are added to China tea, *Thea sinensis* L. "Shirely" is related closely to the opium poppy, and its potential as an opiate is now being investigated.

Some of these teas, such as the harmless African Red or Rooibosch Tea derived from several species of the leguminous genus *Aspalathus*, contain no true China tea but most teas are composed mainly of China tea with specified proportions of other ingredients. Many of the resulting drinks possess a very palatable flavor and have desirable effects upon the health of the consumer. Some are potentially injurious, and the extent to which these beverages do affect man is being systematically studied.

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The Cashew's Brighter Future

The cashew tree, native to Brazil was introduced into India in the 16th century for the purpose of checking erosion on the coasts. India is a world leader in the production and export of cashew nuts, while cultivation of this crop in the western hemisphere has remained negligible. Present demand far exceeds the supply. New developments in processing methods and machinery, and new uses for by-products, particularly cashew shell oil, have stimulated cashew culture in East Africa and Brazil and should give impetus to establishment of this lucrative crop on a commercial basis in other tropical areas.

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The cashew, *Anacardium occidentale* L. (syns. *Acajuba occidentalis* Gaertn.; *Cassuvium pomiferum* Lam.), is known to most Spanish-speaking people as *marañon* or *cajuil;* in the French tongue it is usually *cajou* or *acajou*[2]; and, in Portuguese, it is simply *cajú*, the nut being *castanha de cajú*, and the tree, *cajueiro*. This plant is one of the most intriguing members of the Anacardiaceae. The family, of some 60 genera, includes other important food species such as the mango (*Mangifera indica* L.), the pistachio (*Pistacia vera* L.), the mombins and ambarella of the genus *Spondias*, and, on the other hand, some notoriously poisonous plants, principally poison ivy (*Rhus toxicodendron* L.), poison sumac (*R. vernix* L.), marking nut (*Semecarpus anacardium* L.), poisonwood (*Metopium toxiferum* L.), and guao, a collective name for the several species of *Comocladia* in the West Indies and tropical America. The cashew's close relative, *Anacardium excelsum* Skeels, is a very large timber tree of Central and northern South American forests (7). *A. giganteum* Engl. is common along the Amazon. There are 6 other, mainly Brazilian, species in the genus.

From the economic standpoint, the cashew is an outstanding example of a transplanted species that has become a major crop in a foreign land and remained until recntly a minor dooryard subject in its country of origin and neighboring areas. However, the status it has attained has been in spite of its natural handicaps, horticultural neglect and primitive handling even in its adopted land. It is now on the threshold of an era of improved techniques that promise more widespread production and greater economic importance of both the cashew nut and its by-products.

Description

The cashew tree is an evergreen, of spreading, somewhat straggly habit, low-branched and gnarled in exposed coastal locations (66), but more symmetrical and reaching a height of 35 to 40 feet, with an equal spread, when favorably situated. The bark, normally rough and, on old trees, deeply fissured (121), contains an acrid sap, by most writers erroneously stated to be "milky," (Kirtikar (80) says: "not milky, but thickish and resinous, of a slightly brownish tinge.")[3] which turns black on exposure to the air. The wood of the tree exudes a yellow gum. The leathery, pinnately veined leaves, mainly in terminal clusters, are oblong-oval or obovate, 4-8 inches long and 2-4 inches

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[2]In Haiti, *acajou* is applied to the mahogany (*Swietenia mahagoni* Jacq.). Record and Hess attribute to A. Chevalier (Rev. Bot. Appl. & d'Agr. Tropicale 17:194:713) the assumption that mahogany acquired the name from the use of cashew shell oil to treat the ends of *Swietenia* logs to prevent checking during shipment to France (117).

[3]The sap of other members of the family Anacardiaceae is usually clear until exposed to the air, unlike that of many euphorbiaceous plants which is a truly milky-white latex.

Fig. 1. Cashew flowers, small, star-l ke, yellowish-pink and heavily fragrant, are borne in loose terminal panicles. As is the case with the related mango, th epercentage of fruit set is very low. Photo by Julia Morton.

wide. The highly aromatic (80), yellowish-pink, 5-petaled flowers (Fig. 1) are 1/3 inch across, borne in 6-10 inch, loose, terminal panicles of mingled unisexual and bisexual types. They produce an abundance of nectar and attract honeybees in great numbers (104). The most conspicuous product of the tree is the "false-fruit," the swollen peduncle or hypocarp commonly known as the "cashew apple" (Fig. 2). Pear-shaped or rhomboid-to-ovate (95), and varying from 2 to 4½ inches in length, it has bright-yellow to red, thin waxy skin and a juicy, spongy, muskily-fragrant pulp, which is very astringent until fully ripe when it is subacid to acid, sprightly, and edible. The yellow type is distinctly sweeter than the red. This "apple is actually the receptacle for the true fruit, the cashew nut, which is lightly attached to its apex and which attains full size prior to the enlargement of the receptacle (51). The shell of the nut closely resembles a miniature boxing-glove (92). Only when held with its side indentation upward does it appear "heart-shaped" (as popularly conceived). The generic name is said to be based on the Greek words for "like" and "heart" (10). However, "*ana*," in Greek, usually means "up" or "back."[4] An amusing colloquial name for the nut in West Tropical Africa is "elephant's

[4]According to Dr. A. C. Andrews, Professor of Classics, Univ. of Miami, Coral Gables, Fla., and H. L. Featherly in his *Taxonomic Terminology of the Higher Plants*, Iowa State Coll. Press. 1954.

tick," doubtless due as much to its grayish-brown color as to its proportions: 1 to 1¼ inches long; ¾ to ⅞ inch broad at the base; and ½ to ⅝ inch thick at the stem-end. The shell is smooth, medium-hard, ⅛ inch thick, of a honeycomb structure within. The shell contains a caustic oil which acts as a powerful vesicant on

Fig. 2. The cashew nut attains full size prior to the enlargement of the fleshy receptacle, or "cashew apple," to which it is lightly attached. Photo by Bureau of Plant Industry, U.S.D.A.

skin and prevents the retailing of unshelled cashew nuts. Cracking raw nuts with a hammer, cutting them open with a knife, or cracking with the teeth may result in severe and painful blistering (36, 67).[5] Entirely innocent of the caustic element is the curved, or somewhat kidney-shaped, white kernel which is protected by a thin, easily removed, testa, reddish-brown on the outside and crimson within (80). The kernel is the cashew nut of commerce and is considered one of the most flavorful of nuts.

Origin and Distribution

The cashew tree is native to northeastern Brazil (47) where it occurs wild in extensive stands (15). It has been thoroughly dispersed throughout the tropical lowlands of northern South America, Central America, Mexico and the West Indies and in many of these areas has become naturalized and abundant (21). In the 16th century, Portuguese traders introduced the tree into India, where it was planted along the shore to bind the soil and soon spread as an escape throughout India, Ceylon, Malaya (43), and the Andaman Islands. East Africa and West Africa are also indebted to the Portuguese for the cashew, which has formed forests covering thousands of acres, especially in Mozambique (15), and no other tree is as common as the cashew in Mauritius and the Seychelles (12). It has been more or less casually planted in all warm regions and a few fruiting specimens are found in experimental stations and private gardens in South Florida.

The tree is very sensitive to cold when young (94) but becomes fairly hardy with age and is capable of withstanding short periods of light frost. It is extremely adaptable as to soil, flourishing even in the sand of open beaches, but it grows poorly in heavy clay or limestone. It is found from sea-level to an altitude of 3,000 feet and in regions with a rainfall as high as 150 inches annually or as low as 20 inches (99). When planted merely as a windbreak or soil-retainer, it is so drought-resistant and undemanding as to thrive in arid regions and in ground too poor for most other trees and, because of this ability to withstand neglect, that has largely been its lot. Even now that it is being given some horticultural attention, it is cited as "the most easily cultivated commercial crop." However, for maximum productivity, good soil, preferably deep loam, and adequate moisture are essential (99).

Propagation and Culture

In the past, cashews have been grown almost entirely from seed placed directly in the field, since seedlings do not transplant well owing to a delicate taproot (66). In orchard practice, pits 1½ x 1½ x 1½ feet are dug and left to weather for a month or two. They are filled with soil mixed with rotted manure about 2 weeks before seeding (100). Seeds should be water-tested, those that sink being chosen for planting since they have a higher rate of viability and germinate quickly (139). Two or three seeds are planted together, stem-end up and at a slight incline, and covered with 2-3 inches of soil (100). Germination usually takes place in 15 to 20 days though seeds of low density (i.e., those that float in water) may require as long as 8 weeks (139). Two months after sprouting, the two weakest seedlings are removed, leaving only the strongest one. Thorny branches may be placed as a protective cover over the young plants (99). Where it is necessary to raise seedlings in a nursery, containers used in India are of a type that can be set in the ground and that readily disintegrate, for it is believed that removal will greatly reduce the chance of survival (100). However, in Cuba, baskets of uva-

[5]Drury, *Useful Pls. India*, 1873, mentions a variety of cashew at Travancore with no caustic oil in the shell. No recent record of this innocuous variety has been seen by the writer.

grass, or *caña brava*, (*Gynerium sagittatum* Beauv.) are used and cut away before setting the plant in the ground (154). In Jamaica, it has been found that nursery seedlings can be raised in the ground and transplanted with 90% success if the plant is taken up with a good ball of soil and the top is cut back ⅓ when placing in the field. Severing the taproot several weeks before removal from the nursery apparently has little beneficial effect (67). For soil-binding, as many as 108 trees are planted to the acre (27). In orchards, close-planting (15-20 feet apart each way) has resulted in overcrowding, and spacing 40-50 feet apart is recommended where the soil is such as to promote maximum development (1). The wider spacing also reduces competition for available moisture (35).

Indian government horticulturists are now strongly urging the selection of superior, high-yielding types and their propagation by inarching, or approach-grafting, and air-layering. For inarching, 8-9 month-old seedlings are cut back to half their height and then kept in grass baskets for a month in shade until new shoots appear. The basket is then replaced by a sheet of 100-gauge plastic to retain moisture and the seedling is then joined to a year-old branch of the same diameter on a selected tree, a 2-3 inch strip of bark and inner wood being removed from both the stock and scion and the two bared surfaces being bound together with twine and the junction then being firmly wound about with a strip of waxed cloth. In 90 days, the union should be complete and the grafted plant is gradually separated from the parent. First a "v" cut is made half through the branch an inch below the graft and a similar cut is made in the stock an inch above the graft. Seven or 8 days later, the cuts are deepened and after a further period of 4 days the severing is completed. About 60% take is expected and, while the procedure can be undertaken throughout the year, it is considered best to initiate it ni February and March, with planting in June and July at the beginning of the rainy season (2).

In air-layering, a strip of bark ⅛-¼ inch wide is removed from a year-old branch or pencil-thick shoot of the current season. The bared wood is then wrapped with twine to prevent healing over, covered thickly with moist moss, wood shavings or sand, wrapped securely in a sheet of 100-150-gauge plastic, and the ends tied tightly to the branch with twine. In approximately 75 days, there will be adequate root formation and, again, the separation from the tree is done in three stages: first, a "v" cut half-way through the branch just below the layer; the cut is deepened a week later and completed in another 4 days. Generally 75% success is expected when the layering is performed in February and March, and the plants are set immediately in the field in June and July (2). A nurse-grafted Y-cutting method has been advocated for producing simultaneously a graft and a layer from one shoot (86). Shield-budding was recommended by Wester (112) and is successfully practiced in Malaya on 6-month-old stocks (54). Patch-budding is also feasible (61). In greenhouse culture, cashew trees have been grown from cuttings of mature wood with leaves retained (11). The Central Cashewnut Research Station at Ullal reports that trees produced by the two vegetative methods first described have come into bearing in 2 years from planting, whereas seedlings flower in 3 to 4 years but do not bear a sizable crop until they are 7 years old (19). In some areas the cashew tree dies in 15-20 years (35, 92); in others, it may have a productive life of 40-45 years.

No fertilizing, irrigating or other cultural practices have been established for cashew plantations (99), though leaf mulches and composting are recommended to lower soil temperature and conserve moisture during hot weather. In the first few years, inter-planting of vegetables or other crops may be worthwhile (19).

Varieties

Cashew seedlings present great variation in growth habit, quality of crop and yield. Then, too, the tree cross-pollinates freely and this has further contributed to high variability. There are as yet very few named varieties. Generally, a distinction is made only between those with yellow or red cashew apples, as, for example, the "Amarelo Gigante" and the "Vermelho" catalogued by Dierberger Agricola Ltda., prominent nurserymen of São Paulo, Brazil. The "Hajari" is a heavy-bearing red type of West Bengal (95). The island of Itaparica, off the coast from Bahia, Brazil, has been famed for its "Mantiega," or "butter," cashew (49). An improved variety from Goa is favored for planting in Zanzibar (150). Tests have indicated that very large nuts usually have inferior kernels, are of low density, poor viability and slow germination (139).

Pests and Diseases

The larvae of the cashew weevil or borer, *Mococerynus coripes* (53) (or *Plocaiderus ferrugineus* (126)), bores tunnels in the trunk and roots of the tree, causing leakage of gum which eventually kills the tree (53). The grubs should be removed as soon as detected, the base of the tree sprayed with a solution of 1 lb. BHC wettable powder in 6½ gals. water, and the bore holes filled with the spray (100).

Thrips suck the leaf juices and leave a "scorched" area. Heavy attacks will stunt the growth of young plants. *Idolothrips halidaji* Newm. and *Phloeothrips anacardii* Newm. are reported from Mysore; the red-banded thrip, *Heliothrips rubrocinctus* Giard., occurs in the West Indies (112). They are controlled by spraying with .05% solution of BHC, or "Folidol" (1 oz. in 12½ gal. water) (126).

The caterpillar of the leaf miner, *Acrocercops syngramma* M., is partial to young plants and tunnels through the new leaf tissues. The first signs are winding trails on the leaves. Later the injuries show as patches of whitish blisters. The larvae become reddish when full-grown. Affected trees should be sprayed with "Folidol E. 605" .06% (3 ml. in 1 gal. water) (126).

The tea mosquito, *Helopeltis antonii* S., a reddish-brown bug, punctures the tender shoot tips and flower buds and causes them to turn dark and dry up. Tender, newly formed nuts, if attacked, shed. This pest can be controlled by spraying with a solution of 1 lb. 50% wettable DDT powder in 16 gals. of water (126).

The sporadic leaf-eating caterpillar, *Cricula trifenestrata* H., which has poisonous, stinging hairs, sometimes occurs in swarms and defoliates the tree. It pupates in silky cocoons, and the adult moth is large and reddish-brown (126).

The mealy bug, *Ferresiana virgata*, attacks the cashew inflorescence but can be controlled by spraying with "Folidol E.605" (1 oz. in 12½ gals. water).

Among other pests are leaf webbers, flea beetles (100), spider mites (94) and scales.

Tip die-back or "pink disease" is produced by *Glocosporium* and there may be associated pitting of the surface of the nut (53). This serious disease requires pruning of the affected branches and spraying with 1% Bordeaux mixture (100).

Powdery mildew may appear on young leaves and inflorescence during dry weather and should be dusted with fine sulphur (100). Cashew apples are sometimes attacked by fruit flies (134).

Infestation of Harvested Nuts

Raw cashew nuts, stored in sacks, sometimes in the open waiting shipment and frequently without protection from rain, are subject to infestation through the stem-end and this may go undetected until damage has progressed to the point of heavy loss. Infestation also occurs in the shelled kernels at various stages of han-

dling. Indian entomologists have identified as major insect pests: *Ephestia cautella, Corcyra cephalonica, Tribolium castaneum, Oryzaephilus surinamensis, Necrobia rufipes,* and *Carpophilus* sp., and, as minor ones, *Alphitobius piceus, Tenebroides mauritanicus, Laethetiuns* sp., *Dermestes ater,* and *Psocids.* Four mites, *Tyrophagus castellanii, Aleuroglyphus ovatus, Caloglyphus* sp., and *Cheyletus* sp., are also minor hazards. The Cashew and Pepper Export Promotion Council is formulating sanitary measures and investigating fumigants for better protection of raw nuts and to avoid infestation in factories (105).

Commercial Cultivation and Expansion Programs

The cashew ranks second only to the almond among the nine tree nuts that are of importance in world trade (24). In the first half of 1959, the United States imported 33,170,367 lbs. of cashew kernels, of which 31,620,477 lbs. were from India and 1,016,102 lbs. came from Mozambique. India, the world's chief source of cashews, produces nearly 80,000 tons of the nuts annually and imports 60,000 tons from East Africa for processing (19). Seventy-five percent of Indian production is exported and 25% consumed domestically (146). The ranking cashew states of India at present are Kerala, Andhra, Madras, Mysore and Bombay. A recently inaugurated government program is aimed at establishing the cashew industry in every state, each striving to meet a high quota with the aid of subsidies and cooperative organizations (19). Cashew plantations are intended to cover 50,000 acres on the west coast and 60,000 on the east coast (32). Much barren and forest land considered unfit for other crops is to be utilized under this program (19). Russia, China, Japan, France and Switzerland (19) have recently increased imports of cashews from India, as have Iran and Italy, where importation of cashews was formerly banned to protect the domestic peanut and almond industries, respectively.

In Africa, cashew nuts are produced mainly in the Southern Province of Tanganyika, in Kenya, and in Portuguese East Africa. In the years since the end of the Second World War, plantations have been set out by Asians and Europeans and output has increased considerably (33). One of the latest areas to undertake large-scale cashew planting is Eastern Nigeria where, prior to 1951, the tree was valued only as a soil binder on unused and eroding land, and it is in such waste land that plantations are being established (27). The operation of processing factories in Africa has met with difficulties and the bulk of the crop is still shipped raw to India (33).

In Brazil, a campaign was launched in 1957 to promote the planting of a million cashew trees in the state of Ceará, where a bounty of 5 *cruzeiros* is awarded for each tree set out in plantations of 100 or over, seeds being supplied by the Government. The statement is made by the initiator of the program, Congressman Ernesto Valente: "If the carnauba wax tree has been the tree of life for Ceará, then the cashew tree is destined to play the role of the tree of redemption" (20).

The cashew is commercialized in a minor way in the Malay Peninsula, the Philippine Islands, and in Haiti, in the West Indies. Dr. David Fairchild, in the early years of his plant explorations, became acquainted with the cashew in Jamaica and enthusiastically wrote the Bureau of Plant Industry in Washington of its possibilities as a crop for Puerto Rico, Cuba, and Hawaii (40). Cashew culture has been retarded by various factors, such as the short duration of the crop which leaves field and factory laborers without employment for all but a few weeks of the year (33), the low yield of most seedling trees, and losses from natural predators such as the large flocks of parakeets which feed

on the cashew apples in Central America. But the principal deterrent to widespread cashew commercialization, in spite of the popularity of the nut and the continuing demand, has been the difficulties of processing, together with the conviction that other countries could not successfully compete with India where the most arduous tasks of cashew preparation are performed by plentiful, low-cost, and skilled female labor.

Season, Yield and Harvesting

Cashew trees flower 2-2½ months before the maturing of the fruit crop. If there are heavy rains at blooming time, little fruit will be set (53). In India, the main cashew crop is harvested in April, with a few trees bearing a light crop in October and November (19). In Kenya, the crop from the first bloom is ready in November and December, with a second crop in March and April (53). In Central America, the Bahama Islands, West Indies and Florida, cashews mature in late May, June, and July. Flowers, immature and mature fruits are often seen side by side.

The yield of full-grown seedlings varies from 10 lbs. to a high of 200 lbs. of nuts per tree. An average tree is said to bear 7 lbs. of nuts when 3 years old, increasing to 70 lbs. in the 15th year. Planted 16 trees to the acre the average yield per acre would be 1120 lbs. (53). This figure might be nearly tripled by selection, vegetative propagation, and planting of trees of maximum productivity.

Ordinarily, the cashew apples with nuts attached fall from the trees when ripe and are gathered from the ground (19), the nuts removed by hand and the "apples," for the most part, discarded. Studies have been made to determine if the nuts could be harvested prior to the ripening of the cashew apples in order to avoid depredations of wildlife (birds, bats, monkeys, and squirrels) attracted by their color, aroma and succulence. It was found that, when the nuts changed from green to a full "ash" color and were dry externally, the kernels were fully developed and mature regardless of the partly-ripened condition of the apples and could be harvested, providing the apples were of no importance to the grower. However, nuts intended for planting will not germinate satisfactorily and produce strong plants unless the apples are fully ripe (141).

After collection, the nuts are allowed to dry for 2 days in the sun (19) to reduce moisture content from 16 to 7%, at which stage they have a brittle, rattling sound when shaken together. They are then stored in large sacks for use throughout the year. In Kenya, they have been kept in this way for as long as two years (53). Prior to processing, they are passed through rotary cleaners to remove foreign particles and then are dipped in a water tank, and stored in silos or moist heaps for 12 hrs. to make the shells brittle (79). A moisture content of 7 to 10% in the shells of the raw nuts encourages the bursting of the cells and forcing out of the oil (34).

Processing

About 5% (79) of the cashew nuts produced in India (specifically in South Kanara, Tanjore and South Arcot district of the state of Madras) are simply dried and stored after harvest and then are dried in the sun for 2 or 3 days and shelled without roasting. This results in kernels of inferior quality which can only be used locally. Generally, the caustic oil in the shell is dispelled by heat in some form before the nuts are opened. The nuts may be crudely roasted in coals, hot ashes, or sand, but the most widespread native practice is roasting in shallow pans over open fire. The shells of previously roasted nuts may be used as fuel (28). The nuts must be constantly stirred, for they are prone to scorching and readily catch fire and, in this event, must be

dumped on the ground and splashed with water to extinguish any flames (28). Also, there is no recovery of the expelled shell oil which is becoming more and more important as a by-product. To conserve it, perforated earthenware pans were introduced so that the oil could be collected in receptacles placed underneath. By this means, 50% of the oil is salvaged (146). However, all open-fire roasting is intensely disagreeable due to spurting oil and the fumes which are highly irritating to the eyes, nose, throat, and skin. Further, after roasting, the nuts must be rubbed with sand or ashes to remove residual oil that would otherwise be harmful to the hands of the shellers (28).

A number of Indian processors have adopted rotary cylinders of perforated galvanized iron suspended at an angle over furnaces equipped with chimneys for carrying off the objectionable fumes. The nuts slide slowly down through the cylinder, the oil passes through the holes and is drained away, and, as the roasted nuts emerge at the lower end, they are sprayed with water and transferred to benches to dry and cool before shelling (28). Since there is still much loss of the shell oil in this process, a few large factories have turned to the more advanced method of heating the nuts in baths of cashew shell oil kept at 370-380° F. The nuts, arranged in a single layer in wire trays are submerged and slowly conveyed along the bottom of the tank, then drained as they ride up the curved end and down a discharge chute. They are cooled in a re-

Fig. 3. Indian woman cracking and shelling roasted cashew nuts. The bowl may contain lime, ash, linseed or castor oil into which the hands are frequently dipped to protect them from any remaining trace of the caustic cashew shell oil. U.S.D.A. photograph.

volving conveyor and then preferably centrifuged (79) or agitated in vermiculite to remove residual oil. Vents or flues are connected to the tanks to evacuate fumes. From 85 to 90% of the oil is salvaged from the shells by the oil-bath process. Much of the 10-15% remaining in the shells may be salvaged after cracking by treating the broken shells with superheated steam. In fact, a steam process for the treatment of the whole raw nuts has been patented. It consists of placing the nuts (or the broken shells) in a series of connected vertical tanks into which is fed steam of 500-700° F. and 5-20 lbs. pressure per sq. in. The shell oil and condensed steam are drawn off at the bottom of the tanks and the oil is considered to be of better grade than that obtained by other methods. The treatment may be of an hour's duration followed by 10 min. of saturated steam maintained at the same pressure (34).

Shelling

Shelling of the nuts is almost entirely a hand operation (Fig. 3). The work is unpopular and it is difficult to find people willing to do it. In India, it is usually done on stones embedded in the ground and by squatting women using wooden mallets, and there is considerable breakage of kernels (66). It is customary to dip the hands frequently in lime (134), ash, linseed oil, or castor oil (30) to protect them from any trace of shell oil remaining, especially after the more primitive methods of roasting.

A simple, motor-driven machine for opening unroasted cashew nuts was introduced in late 1958 by Mr. F. Lawton of Amaputa Minerals, Tanganyika (Fig. 4). An operator, with hands protected by a coating of barrier cream, places a nut in a plier-like gripper which is then moved against a small circular saw which cuts a groove around the shell. When a few pounds are so grooved, the operator levers the shells open with a special implement (Fig. 5). As the inventor says, the process is "much like opening an oyster." It is stated that with this inexpensive equipment, one man can open 1,000 nuts an hour without kernel breakage (124). Mr. Lawton has gone a step further in improving his invention and plans to place on the market a machine which will open the nuts and separate the shells from the kernels mechanically (81).

One of the great advantages is that the raw shells can be crushed to expel the phenolic oil in its natural form and with the maximum recovery (124).[6] The raw kernels may be kept in cold storage for later processing (79).

Roasting of Raw Kernels

When raw kernels are obtained by the above-described or other methods, they may be roasted in olive oil or peanut oil in 5-lb. lots placed in metal trays over a coal furnace. The trays are taken out 3 or 4 times at 5-minute intervals, shaken and replaced until the roasting is half completed. The kernels are then mixed in a bucket with a small amount of liquid paraffin, replaced on the tray and given another 5-minute roasting, sprinkled with a solution of salt, gum acacia, and water, and finally reheated to remove excess moisture (79).

Husking, Grading and Packing

After roasting in or out of the shell, the kernels must be dehusked, that is, the reddish-brown testa is removed by hand and this is a quick and easy operation. If the kernels are to be put in storage for a time, the testa may be left on as it helps to keep them fresh for a longer period (79, 146). They may be fumigated with methyl bromide to prevent insect infestation.

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[6]In 1942, the United States Government ruled that cashew kernels would be permitted entry only if the greater part of shell oil were removed before cracking. This presents an obstacle to the importation of kernels extracted by Mr. Lawton's method.

The husked kernels are sorted by size, the highest grade being "210" (210 kernels per lb.). Lower grades are "240," "320," and so on, down to "500," and, finally, to the split, broken, or scorched pieces (28). They are then placed in a humid chamber to secure a desired moisture content—if too low, the kernels be-

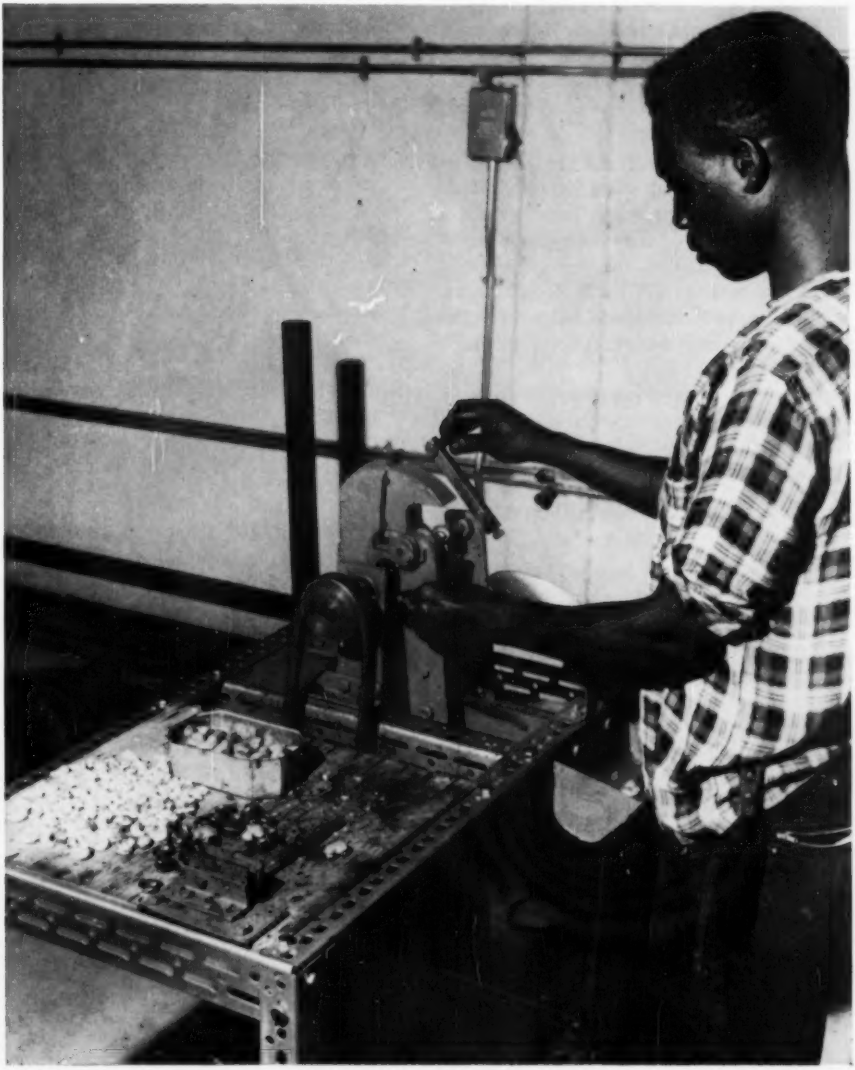

Fig. 4. A cashew-opening machine invented by Mr. F. Lawton of Amaputa Minerals, Tanganyika. Operator, with hands protected by barrier cream, places raw nut in gripper and moves it against a circular saw which cuts a groove around the shell. Photo Courtesy East Africa Railways & Harbours.

come brittle; if too high, they invite insect attack (79).

The Cashew and Pepper Export Promotion Council has established a Code of Procedure for the issuance of health certificates for cashew kernels which have passed tests for purity (freedom from insect infestation, shell fragments and cashew shell oil) and have a free fatty acid content not exceeding 3% (72, 73).

For export, the kernels are packed in 25-lb. tins lined with oiled paper, or 112-lb.-capacity wooden boxes lined with tin. If vacuum-packed, they keep well for 9 months, but if in CO_2 the storage life may be only 3 months (79). In recent years, it has been proposed that cashews for export be packed in corrugated cartons lined with metal foil (32). Distributors, after processing and seasoning of kernels to suit consumer tastes, package for retailing in small cans, cellophane or plastic bags.

Food Value and Uses of Cashew Kernels

Cashew kernels, sugared or salted (146), are consumed primarily as table nuts and some are used in bakery goods and confectionery. In tropical countries, cashew nuts are eaten with palm sugar and coconut, added to curries and stews, or they may be combined with bean flour and fried in oil (66). In West Africa, the nuts are often boiled in soup (44). Ground cashews are mixed with cocoa to produce an adulterated chocolate (136). In Guatemala, a beverage called *"orchata de marañon"* is made of ground cashews mixed with water (136). Broken kernels are made into cashew butter and are also used to flavor Madeira wine (140). Crumbs and husks are sold as chicken feed (79).

The chemical content of the husks is reported as: moisture, 8.1%; protein, 7.6%; fat, 12.3%; carbohydrates, 59.2%; fiber, 11.0%; ash, 1.8% (84, 146).

Anacardic oil, derived from cashew kernels, is light-yellow (116) and similar to almond oil but is considered too expensive to be competitive with other fine culinary oils (23). It is used to some extent to harden chocolate (53) and it is given medicinally as an antidote for irritant poisons (45, 116). It has also been used as a demulcent in the form of an emulsion (116).

In the 42.2% anacardic oil obtained by ether extraction, the acids (glycerides) are reported as: oleic, 73.77%; linoleic, 7.67%; palmitic, 6.4%; stearic, 11.24%; lignoceric, 0.5%; unsaponifiable matter, 0.42%. Saturated acids equal 18.2%; unsaturated acids, 81.8%. The fat-free kernel, contains 17-18% globulin, called anacardein, composed of: carbon, 50.41%; hydrogen, 7.32%; nitrogen, 19.30%; sulphur, 0.78%; oxygen, 22.19% (74). Amino acid composition of cashew nut globulin has been reported by scientists at the Central Food Technological Research Institute, Mysore (137).

Food Value and Utilization of Cashew Apples

In parts of the West Indies and tropical America, where the cashew tree is grown only casually, it is generally the practice to salvage the "apple" and discard the nut (134) (Cf. Table 1). In Brazil, the cashew apple is rated foremost of native fruits (63) and large heaps are seen in the native markets during *"cajú"* season (66). The "apple" is commonly sucked raw out-of-hand, the juice being squeezed into the mouth and the residual fibrous mass cast aside. For the table, cashew apples may be sliced and stewed, or used in pies or made into fruit soup as is done in Venezuela (92). Inferior types that are still astringent when ripe are eaten with salt (116) to avoid unpleasant throat irritation (80). In tropical America, the juice is enjoyed and is used in ices and jelly. In Bolivia, it is popularly believed to stimulate the brain and develop the memory (106).

TABLE I

COMPOSITION OF CASHEW APPLE (PER 100 GRAMS)

	Moisture	Ether extract	Crude fiber	Nitrogen	Ash	Calcium	Phosphorus	Iron	Carotene	Thiamine	Riboflavin	Niacin	Ascorbic acid: Total
	gm.	gm.	gm.	gm.	gm.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
(96) El Salvador	85.8	0.10	0.6	.149	.33	1.5	19.3	0.67	.240	.023	.015	.480	146.6
	88.7	0.05	0.4	.125	.28	1.8	19.9	0.19	.022	.015	.013	.478	231.3
(97) Costa Rica	85.0	0.17	1.0	.127	.32	1.6	15.3	0.26	.476	.019	.020	.474	166.5
	86.7	0.23	0.5	.101	.33	0.9	16.9	0.66	.008	.018	.019	.514	200.3
(98) Guatemala	84.4	0.50	0.7	.162	.34	3.1	21.4	0.33	.742	.015	.016	.539	347.8
(102) Cuba	—	—	—	—	.19	4.2	6.1	.69	.00	.00	.02	.13	372.0
(84)					.21	5.4	11.6	.71	.03	.03	.04	.31	312.6

Note: Jain, *et al.*, report malic acid content of .35% and reducing sugar, 10.5-12.5% (75).

Preservation of cashew apples in sirup in metal cans or glass jars is attempted in a limited way, as in Cuba, but the market for this product is not large. Cashew apple juice may be made into vinegar (75). In Cuba, Costa Rica, Brazil, the Philippine Islands and India, cashew wine is bottled commercially. The wine, on distillation, yields a good brandy which is produced under government control in Portuguese East Africa and in Goa (66), but is subject to prohibition in some of the Indian states (99).

In India, where it is estimated that 250,000 tons of cashew apples are harvested annually, 85% of the crop goes to waste (76). Of the 15% utilized, some is fed to swine (19). The Central Food Technological Research Institute at Mysore has done much experimentation in an effort to develop processes for converting the cashew apple into beverages and preserves with consumer appeal. Desiring to first eliminate the astringency and acridity attributed to 35% tannins and 3% of an oily substance, they have tried many treatments, but have found that the most effective treatment is steaming under 5-15 lbs. pressure for 5-15 minutes, followed by thorough washing.

To obtain juice for beverage purposes, the steamed and washed fruit is put through a mechanical extractor or press. A cashew apple crushing machine for juice extraction has been designed by engineers of the Bureau of Plant Industry, Manila (50). There may still remain in the juice some undesirable elements which

Fig. 5. After a few pounds of nuts are grooved, the operator levers them open with a special tool. One thousand nuts can be opened in an hour without kernel breakage. The shells are separately processed for maximum recovery of the valuable cashew shell oil. Photo Courtesy East Africa Railways & Harbours.

may require the addition of casein, gelatin, pectin or lime juice, and straining or centrifuging. Thereafter, sugar and citric acid are added to achieve 15° Brix and acidity of .4%. The juice is then boiled for a minute and pasteurized in bottles or cans. Variations that may be achieved are: nectar, or "cloudy juice," spiced juice, concentrate, and blends with the juices of other fruits such as pineapple, orange, grape, etc., and all are recommended for use in carbonated beverages (76).

The Institute has developed tested formulas for canning cashew apples in sirup, alone or with pineapple rings, also for making wine (53), sirup, jam (114), chutney and candied cashew apples (113), the last two products being considered the more acceptable for export. Raw, green cashew apples, after steaming and then brining for a week, may be pickled (76).

Cold storage studies by K. K. Singh and P. B. Mathur show that cashew apples, which are highly perishable, can be kept at 32-35° F. and relative humidity of 85-90% for 5 weeks, though there is some loss of vitamin C (125).

Cashew Nut Shell Oil

Cashew nut shell oil, or liquid, is one of the few major economic sources of natural phenols (90). It is 90% anacardic acid, an *ortho*-hydroxybenzoic acid with an unsaturated side chain (146), and 10% cardol. The composition varies according to the heat treatment employed to expel the oil. (32, 34, 79).

In tropical medicine, cashew shell oil has served as a rubefacient and vesicant in treating leprosy, elephantiasis, psoriasis, ringworm (45), warts, corns, and cracks in the soles of the feet (24); and it has even been used, as a drastic beauty aid, to remove freckles (132) and also to peel the skin from the face so that a new and more attractive skin might grow in its place (45). This entails blistering and blackening and 2 weeks seclusion but has been borne by West Indian women for the sake of vanity (40). In West Africa, it is employed in decorative tattooing and is sometimes placed in tooth cavities (44). Since the oil is a powerful irritant, its use is hazardous. Taken internally, it causes severe gastro-enteritis with loss of control of the muscles and interrupted respiration (23). Subcutaneous injection even of large doses may not be lethal but produces stupor, paralysis of the extremities and diarrhea (36).

The oil has been much used primitively to protect posts, floors and rafters from termites, and as a waterproofing and preservative for fishing lines, nets, boats (99), bamboo screens (151) and light woodwork. In more modern usage, it has served as an insect-repellant for bookbindings. A dilute extract applied as a gloss on vanilla beans is believed to be responsible for the handlers' discomfort known as "vanilla itch" (36, 145).

Industrial uses, resulting largely from the investigations of M. T. Harvey and S. Caplan of the Harvel Research Corporation (an American concern), dating from 1926, have advanced it to a status of growing importance as a major by-product of the cashew industry (146). Distillation and polymerization of the oil yields materials highly resistant to the action of acids and alkalis, solvents and oils, and which enter into the composition of a great diversity of products including typewriter rollers, insulation, automobile brake linings, clutch facings (exceedingly resistant to high friction temperature) (69), magneto armatures for airplanes (140), floor tiles and cold-setting cements. Resin, obtained by condensing the shell oil with formalin in linseed or tung oil, is used in the preparation of laminating resins, varnishes, and baking enamels (90), some of which can withstand caustic soda and boiling nitric acid (89). They have insulating properties of special value in electrical machinery, transformers, etc. (70).

The oil is also an ingredient in various

adhesives, inks, paints, oilcloth, and finishing and waterproofing for paper and cardboard, and it has great potentials in the preparation of molding powders in the plastics industries (89). Cashew shell oil polymerized with formalin and hydrochloric acid yields cation exchange resin, after reaction with sulphuric acid, which is used for softening water in boilers and air-conditioners (52, 101).

Many processes have been patented for the extraction, polymerization and distillation of cashew shell oil to obtain purified cardanol free of darkening compounds and more readily soluble in drying oils (25, 26, 57, 58, 60). A patented process for eliminating the natural sulphide content causing dermatitis is applicable also to the caustic oils of the marking nut, the Japanese lacquer tree (*Rhus vernicifera* DC.) and other members of the Anacardiaceae (59). Decarboxylation treatment for cashew shell oil (converting the anacardic acid into anacardol without undesirable foaming) was patented by N. E. Berry and R. E. Kremers in 1946 (17).

A mixture of 5% cashew shell oil and 95% kerosene or diesel oil is an effective mosquito larvicide (146).

In India alone, it is estimated that 15,000 tons of the shell oil can be recovered annually. In the first half of 1959, India exported 5,670,200 lbs. of cashew shell oil: 2,841,100 lbs. to Great Britain; 1,619,800 lbs. to the United States; and 1,010,700 lbs. to Japan. Mozambique exported to the United States about 50% as much as India in the same period.

Sundry Food, Industrial and Medicinal Uses of Cashew Tree Products

Very young cashew leaves are used raw as a flavoring for rice in Java and Malaya (23). Young shoots and leaves are eaten in Africa (152) and in the Philippines where analyses have shown them to be inferior to most greens in calcium and iron content (22, 116). Since they are astringent, they are believed to alleviate diarrhea, dysentery and hemorrhoids (116). Mature leaves are crushed and used as poultices for burns and skin ailments (23). Fragmented leaves are used for cleaning the teeth and are believed to prevent decay (39).

The sap of the tree turns dark on exposure to air and is used (as is the cashew shell oil) as a marking ink on cotton. It is waterproof but soluble in alcohol or ether, and it is less irritating than the oil from the marking nut (23) which has caused dermatitis when used to mark clothing. Natives of the tropics use the sap as a flux when soldering metals (39).

A yellow, amber-like (80) gum (Fig. 6) called *Gomme d'Acajou*, or cashawa gum (140), exudes from incisions in the tree or seeps out in quantity when old trees are about to die (112). It has some cardol content and is capable of blistering but is used in varnishes to protect books, wood carvings, etc., from insects. It is employed as a substitute for gum arabic in adhesives and other products and is

Fig. 6. Yellow gum which exuded from injured trunk of cashew tree is brittle and amber-like. Obtained in quantity from old, dying trees, it is used as substitute for gum arabic. Photo by Julia Morton.

commonly used as a mucilage by South American bookbinders (40).

The wood of the cashew is grayish (129) to reddish-brown, soft to moderately hard (23), has poor grain, weighs 30-39 lbs. per cubic foot (65), and is used for tea chests (46), packing cases, boatmaking (99), yokes and wheel hubs (51). It is good for both firewood and charcoal. The bark, reported to contain 9.4% tannin, has been used for tanning leather (23) and yields a yellow dye (46).

Medicinally, the wood is astringent (65); the roots of the tree are purgative (23) and are sold by purveyors of medicinal herbs in Cuba (120). The bark is used for sore gums and toothache. A decoction of the bark is used for diarrhea and as a mouthwash for thrush (23); an infusion is given in cases of *"diabetes insipidus"* (45, 116) and is applied externally for skin eruptions (120) and for syphilitic swelling of the joints (132). In Brazil, tincture of cashew bark is given orally to lower blood pressure (38). In some cases of malarial fevers, cashew bark has proved more effective than quinine (153). Extracts of the bark and inflorescence are given in small doses as antidotes for snakebite (45).

Raw juice of cashew apple is prescribed for stomach disorders, is given to arrest vomiting, and is used as a gargle for sore-throat (108). It is reputedly, a remedy for the disease known as "dirt-eating" (51). The juice, fresh or distilled, is said to act as a strong diuretic (23) and is considered of benefit to patients with uterine complaints and dropsy (45, 145). It is also supposed to possess sudorific and antisyphilitic properties (116). Cashew wine is regarded in Brazil and Cuba as an excellent remedy for chronic dysentery (82). The spirit is applied externally to relieve pains of neuralgia and rheumatism (45).

Rural people of Cuba attribute aphrodisiac properties to pulverized, roasted cashew kernels mixed with a little sugar (120). In India, the bruised nut has been employed as an irritant to induce abortion (116). There is a superstitious belief in Trinidad that a collar of cashew nuts will cure distemper and other ailments of dogs (40).

In Haiti, the Dominican Republic, and elsewhere, roasted cashew nuts are often used for heads on maracas, on dolls or other novelties made of colored seeds, or on "swizzle sticks" for stirring mixed drinks in bars. Faces are carved to represent mouth and eye-sockets and the red-and-black seeds of the rosary pea (*Abrus precatorius* L.) are generally inserted for eyes. When so fashioned, they are sometimes called "monkey nuts" (142). These are primarily sold to tourists as souvenirs and many have been brought into the United States by travelers. They have also been imported in quantity for use as "favors" at banquets (109) and many have been sold by novelty shops in Florida (138). However, in late 1958 the United States Public Health Service confiscated some cashew-headed swizzle sticks which had caused a rash among Georgia school children because of improper roasting and seepage of cashew shell oil through the openings in the shell (18). Much consternation was aroused by publicity which brought out the poisonous character also of the rosary pea "eyes." Haitians have accordingly switched to imitation cashew heads made of mahogany with colored plastic for eyes (48).

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Steroidal Sapogenins. LVIII. Steroidal Sapogenins from the Joshua Tree

The Joshua tree, Yucca brevifolia, is distributed over parts of Arizona, California, Nevada, and Utah. A study of its steroidal sapogenins showed that the leaves contain practically none; the wood, small amounts of smilagenin; the seeds high amounts of hecogenin and tigogenin.

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The Joshua tree, *Yucca brevifolia* Engelm., forms extensive open forests of dichotomously branched, small trees (Fig. 1) in the region from extreme southwestern Utah southward into Arizona and westward across southern Nevada into southern California. These forests usually occur at altitudes of 3,000 to 5,000 feet.

The number of inflorescences on the trees varies from year to year, but when abundant they form a desert crop grown without human assistance. Cattle and sheep are known to relish the flowers (15). Attempts to find a practical human food use for the flowers reported by Woodbury et al. (15) were not successful because of a soapy flavor of the delicious-looking, otherwise delicately-palatable cooked flowers. The chemical analysis indicated a nutritive content about equivalent to that of many vegetables or fruits.

A search for ways and means of utilizing the huge crop of Joshua tree flowers led to the studies reported herein. The search was further stimulated by the meetings of the International Arid Lands Conference at Albuquerque, New Mexico, in 1955 that emphasized the need to utilize the deserts of the world. We then decided to initiate preliminary studies on the character of the saponins that produced the soapy taste in the flowers. A preliminary sample, taken May 21, 1955 from the Beaver Dam Mountains in Extreme southwestern Utah, indicated a sufficiently high sapogenin content to warrant further investigation.

The Joshua Tree

The tree yucca was first described and named *Yucca draconis* var. *arborescens* by John Torrey (8) in 1856 from specimens that had been collected on the Pacific Railroad explorations (9). In 1871, while revising data on the genera Yucca and Agave, George Engelmann described and named the same tree *Yucca brevifolia*. It has also been placed in a separate genus, *Clisto-yucca*. The common name, according to tradition, was given by early day Mormons, who asserted the trees with their peculiar shaped arms were, like the Biblical Joshua, pointing the way to the Promised Land.

Joshua trees are well distributed over parts of four states within the area shown on the map (Fig. 2). In many places the trees form open groves or forests. In other places, they may be scattered over the landscape. They are far from continuous within their range, being interrupted in many places by the absence of suitable conditions. They do not grow in the bottoms of the low arid basins nor on the steep slopes of the mountains. They thrive best on the higher gravel slopes that skirt the mountains, usually in definite belts or zones. This belt varies in altitude, usually in conformity with the

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Fig. 1. Joshua tree (*Yucca brevifolia*) forest.

base level from which the slopes rise.

Both observations and measurements indicate that the Joshua is a slow-growing tree. In Joshua Tree National Monument, studies of growth rates conducted over a period of years by members of the Monument staff under the leadership of Chief Ranger H. L. Earenfight, show that the growth rate of seven different trees averaged from 1.36 to 3.48 inches per year. The greatest rates of growth occurred in trees about five to ten feet in height.

The six-chambered capsules, one to two inches in diameter and two to three inches in length may be full of thin black seeds. Each seed is about 0.25 to 0.5 inch in diameter and 0.06 inch in thickness. During development many of these seeds are eaten by insect larvae (presumably yucca moth) and usually only a few mature. Ripening capsules are often eaten by rodents.

The number of inflorescences that develop vary from year to year, from tree to tree, and often from place to place. During favorable years there may be heavy crops; in unfavorable years there may be few. A relatively heavy stand in eastern Nevada about 15 to 20 miles west of Caliente, covering roughly 50,000 acres, was examined on April 17 and 18, 1957. In a favored spot, where the trees were thrifty and relatively dense, a count on 100,000 square feet showed 110 relatively large trees bearing 892 flower panicles. This was a typical heavy crop. In a moderately dense stand a half-mile distant, an area of the same size yielded 95 slightly smaller trees bearing 192 panicles. The flower heads usually weighed between one and two pounds; extra large

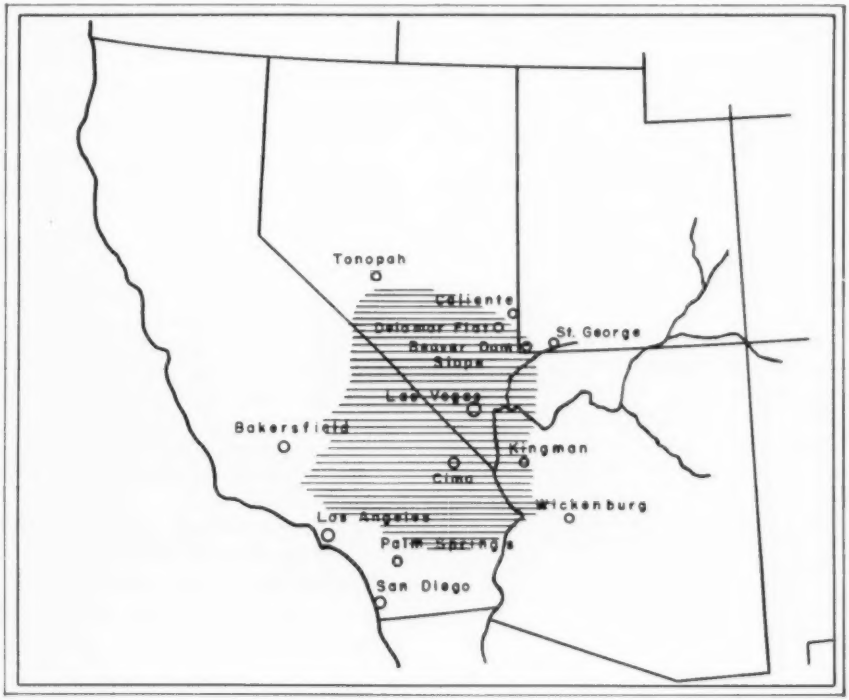


Fig. 2. Map showing important Joshua tree area.

ones reached three pounds. It was roughly estimated that an average of the two stands might contain one tree per 1,000 square feet and bear five panicles of two pounds each, or ten pounds per tree.

A similar stand covering about the same area on the western foothill slopes of the Beaver Dam Mountains in southwestern Utah, examined on April 19, 1957, had passed the fresh blooming period, and was developing large green capsules. A sample area of 10,000 square feet in a medium dense stand yielded a count of 20 trees, 26 inflorescences, and 88 capsules. In a denser stand containing thrifty trees, 20 to 30 capsules per inflorescence were commonly found. However, inflorescences of 40 capsules were occasionally found, and in one case more than 50 occurred.

Steroidal Sapogenins

Analytical Methods. Samples of the various Joshua tree fractions were collected in Utah and Nevada, packed in plastic bags and shipped by air express to the Eastern Utilization Research and Development Division. The material, even the flowers, arrived in excellent condition. The following fractions were made: leaves, which were subdivided into green (younger) and brown (older) fractions; buds, flowers, and their respective stalk fractions; fruits which wherever possible were separated into seeds and empty capsules; and wood. A diagrammatic sketch showing the various plant fractions is shown in Fig. 3.

All the plant fractions were immediately dried in a forced draft hot air oven

at a temperature of 80° C. The dried fractions were then ground to pass a 1 mm. screen. The preferred quantity of sample for sapogenin analysis was 100-200 grams. In many cases quantities as low as 5-10 grams were used with suitable modifications in technique (4). The sample was suspended in 1.5 N HCl, refluxed five hours, and filtered. The insoluble residue containing the sapogenins was washed with bicarbonate solution and water until neutral and then dried at 80° C. The dry residue was placed in a Soxhlet extractor and continuously extracted with heptane for 24 hours. On concentration of the heptane solutions 90-95% of the total sapogenin content could be obtained in crystalline form. The sapogenins were filtered, dried and weighed. Infrared (1, 10) and paper chromatographic analysis (4) showed that only smilagenin, tigogenin, and hecogenin were present. Smilagenin, when present, was always found as the sole constituent, but tigogenin and hecogenin were often present as mixtures. Estimation of the intensity of the infrared carbonyl band gave values for hecogenin which were in reasonable agreement with data obtained by direct isolation of hecogenin by the Girard T reagent (6). Tigogenin could then be obtained by subtracting the hecogenin value from the total sapogenin.

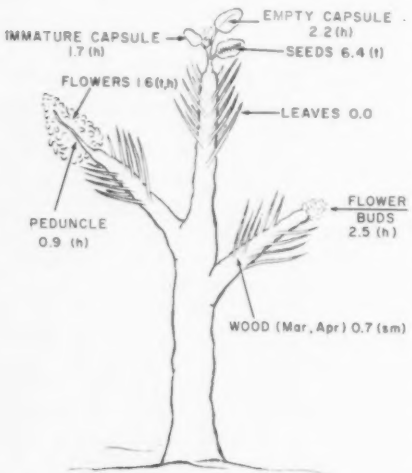


Fig. 3. Diagram showing average sapogenin content in various parts of Joshua tree. (t = tigogenin; h = hecogenin; sm = smilagenin)

Distribution and Seasonal Variation of Sapogenins in the Joshua Tree. Table 1 presents the complete data on the seasonal variation of the sapogenins in the Joshua tree. Fig. 3 shows the average sapogenin content of the various plant parts. On the whole the data collected on samples in two different years and from two different locations were in reasonable agreement. Only three sapogenins were found: smilagenin in the wood and mixtures of tigogenin and hecogenin in varying proportions in the floral parts and in the capsules and seeds. Surprisingly, no sapogenin was found in the leaves. This point will be discussed below.

Chemical Structure of the Sapogenins. The chemical structures of the three sapogenins found are shown in Fig. 4. It should be noted that, in the plant, sapogenins are never found as the free steroid but are combined with sugars through glycosidic linkage at the three position (1, 7) to form the water-soluble saponins. It will be noted that tigogenin and hecogenin are identical except that the latter has a carbonyl group in position 12 of ring C. Hecogenin can be converted easily by chemical means to tigogenin; similarly, enzymes capable of oxygenating C-ring deoxy systems are well known. Hence, it is not surprising that tigogenin and hecogenin should be associated, and, in fact, the association of these two sapogenins is well known (5, 10, 11, 12, 13). Smilagenin has a different A/B ring fusion from that which is found in tigogenin or hecogenin and there is no simple chemical or biological means of converting the *cis* A/B fusion of smilagenin to the *trans* A/B fusion of tigogenin. Marker and his associates, working with the whole plant, found mixtures of A/B

STEROIDAL SAPOGENIN CONTENT OF THE JOSHUA TREE[1]

TABLE I

Date and Location[2]	Wood	Leaf	Inflorescence: Flower Buds: Beginning	Inflorescence: Flower Buds: Developed	Inflorescence: Mature Flowers: Peduncle	Inflorescence: Mature Flowers: Flowers	Fruit: Capsule with Seed	Fruit: Empty Capsule	Fruit: Seed
3/10/58 BD	0.5(sm)	0	2.2(h)						
3/20/56 BD	1.2(sm)	0	0.9(0.4)			2.0(0.4)[3]			
3/26/58 BD	0.1(sm)	0		2.1(0.4)					
	1.2(sm)			1.7(0.3)					
4/ 9/56 BD			3.1(0.3)	2.6(1.0)	1.0(0.4)				
			0.5(h)	4.3(0.4)	1.6(0.4)				
					0.9(2.3)	1.2(1.0)			
					0.4(0.4)	0.8(0.4)			
4/12/58 BD	0.6(sm)	0							
	0.6(sm)								
4/12/58 DF				2.7(0.7)					
4/23/56 BD	0.9(sm)	0			1.1(0.7)	1.6(0.4)	1.0(0.7)[5]		
					1.0(1.0)	4.4(1.0)			
					0.5(2.3)	0.9(2.3)			
4/26/58 DF	0	0		2.4(1.0)	2.1(0.4)				
				2.2(1.0)	1.3(0.5)				
					0.6(h)	1.2(0.7)			
						1.9(1.0)			
4/26/58 BD	0	0				1.7(2.3)			
5/ 3/57 DF		0					1.0(0.3)		
BD		0						2.6(2.3)	5.0(t)
5/ 7/56 BD				0.9(1.0)[4]	2.2(1.0)[4]			2.3(0.6)	8.1(t)
5/10/58 DF	0	0		0.3(0.2)	1.2(1.0)				
				0.2(0.3)	1.3(1.0)				
5/23/56 BD	0.1(sm)	0		0.9(0.4)[4]	1.6(0.7)[4]		2.5(0.3)	1.9(0.1)	4.5(2.3)
								1.9(0.3)	5.7(2.3)
6/ 1/58 DF	0	0		0.3(h)	1.6(1.0)[4]			2.0(h)[5]	8.0(t)[5]
								1.9(h)	8.9(3.0)
7/19/56 BD	0.1(sm)	0						1.8(2.3)	
8/ 1/58 DF	0				1.9(0.3)[4]				
10/20/58 BD	0.5(sm)	0							
1/ 5/59 BD	0							1.0(h)[3]	8.7(3.0)[3]
4/12/58 DF									

[1]Total sapogenins in percent of dry matter. Figure in parentheses is the ratio, tigogenin/hecogenin; (t) means all tigogenin; (h) means all hecogenin; (sm) means all smilagenin.

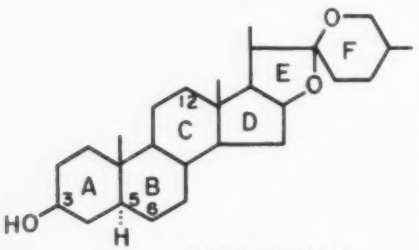
[2]BD means Beaver Dam, Utah; DF means Delamar Flat, Nevada.

[3]Remains from previous year.

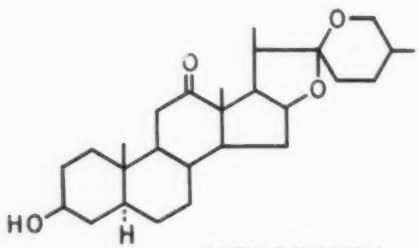
[4]Dry flowers and peduncles.

[5]Immature.

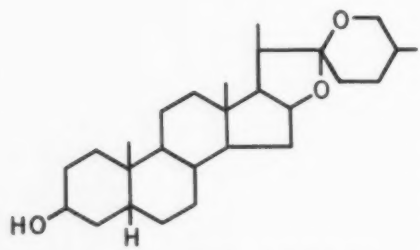
trans and A/B *cis* sapogenins, and on this basis postulated that the two forms are interconvertible (5). In the present study we have been unable to demonstrate the occurrence of the Δ^5-unsaturated precursor. Furthermore, extensive studies cursor. Furthermore, extensive studies of carefully separated plant fractions (10, 11, 12, 13), indicate that in any one tissue A/B *trans* and A/B *cis* sapogenins are never found together. The question of the biogenesis of the two forms remains open.



TIGOGENIN



HECOGENIN



SMILAGENIN

Fig. 4. Structure of tigogenin, hecogenin, and smilagenin.

The data shown in Table 1 and Fig. 3 show several distinct features. Smilagenin is found only in the wood tissue and only during March and April, coincident with the early phases of the reproductive cycle. At no period were significant quantities of sapogenins found in the leaves. Although Table I shows the content as zero, this is not strictly correct. Our analytical procedures are insensitive to sapogenin levels below 0.1-0.2%. In most cases, the leaf samples had quantities of sapogenin between 0.01 and 0.1% which were identified as mixtures of hecogenin and tigogenin. In contrast to our experience with the leaves of many other *Yucca* species (10, 11, 12, 13), saponins are not concentrated or stored to any extent in the leaf of *Yucca brevifolia*.

The largest concentration of saponins takes place in the reproductive parts of the Joshua tree. Flower buds and flowers average between 1.5 and 2.5% total sapogenin as a mixture of hecogenin and tigogenin. On the whole, hecogenin is predominant although the mixture was found in virtually all samples analyzed. A striking increase occurs in the sapogenin content of the fruits. The capsules contain from 2-3%, which is almost exclusively hecogenin. In the seeds the content rises strikingly to values which range between 4.5 and 9.0% with tigogenin now often the exclusive and always the predominant sapogenin. This appears to be a case of biological reduction of the 12-carbonyl group in hecogenin to a methylene moiety in tigogenin.

The large concentration of saponin in the seed of *Y. brevifolia* is not an isolated occurance; a number of *Yucca* and *Agave* species exhibit similar behavior (14). The saponin concentration of Joshua tree seeds, assuming that four sugar moities are combined with the steroid (2), would, in the highest cases, be about 18%, an extraordinarily high value for a substance

with no known metabolic functions. In this connection, a most interesting review by Fraenkel (3) points out that a number of secondary plant substances, including glycosides of steroidal alkaloids which have structures very similar to the steroidal saponins, may serve as general insect or animal repellants and in some cases also as attractants for specific insects. It is of interest that certain moths are invariably found in Joshua tree flowers and their seed capsules.

Utilization of Joshua Tree Sapogenins. Hecogenin is a commercial source of cortisone. Tigogenin can be converted to androgenic and estrogenic hormones. The flow sheet outlines a process by which both sapogenins could be obtained. It should be emphasized that, because of the large development of *Dioscorea* tubers as a source of steroids, bulk steroids such as the above now command a relatively low price. Consequently, the process shown will not be economic unless collection costs are low and large quantities of suitable plant material are available.

FLOW SHEET

FOR

PREPARATION OF HECOGENIN AND TIGOGENIN FROM JOSHUA TREE

Joshua Tree Buds, Flowers or Fruit

1. Macerate tissue
2. Add water and press

Juice — *Bagasse*—dry—possible cattle feed

3. Add sulfuric acid to pH of 1.0
4. Heat near boiling 4-6 hours
5. Cool and decant supernatant liquor from sludge

Sludge (partially hydrolyzed saponin) — Acid liquor (discard)

6. Slurry with 3N sulfuric acid and boil 5 hours
7. Cool, decant liquor from sludge

Crude sapogenin — Acid liquor (reuse several times)

8. Neutralize with soda ash
9. Dry and grind sludge
10. Extract sludge with boiling hexane or heptane
11. Decant solvent from insolubles

Solution (hecogenin + tigogenin) — Sludge (discard)

12. Treat with decolorizing carbon if necessary
13. Concentrate until crystalization just begins

Insoluble crystals hecogenin — Soluble fraction *tigogenin*

14. Concentrate

Crystal *stigogenin*

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Quadrangular Bamboo

ROBERT E. PERDUE JR., and JOHN L. CREECH[1]

Bamboos are widely distributed in tropical and sub-tropical regions and have a multitude of uses. In most important bamboo-producing areas they fulfill the purely utilitarian needs of the people. They provide food, clothing, shelter, basic implements required to maintain daily existence, and simple items of comfort. Bamboo, as a part of the landscape and a frequently encountered object of daily life, provides a favorite subject for the artist, but the craftsman constructing a building or fabricating a useful object as a rule gives little attention to making use of its aesthetic properties. The Japanese, however, are exceptions, for they take unusual advantage of the artistic qualities of bamboo, especially in the interior decorative construction of buildings. The production and utilization of artificially induced quadrangular bamboo culms exemplify the creative use of bamboo in Japan. Quadrangular culms have been described and illustrated in a number of Japanese publications, but so far as we know, these unusual artificially induced forms have not received more than passing mention in western-language publications.

The Japanese use only *Phyllostachys pubescens* Mazel ex. H. de Leh. (*P. edulis* H. de Leh.) for production of quadrangular culms. Other species could undoubtedly be used, but no other Japanese species produces culms sufficiently large to be so well-adapted. In Japan *P. pubescens* culms attain diameters up to a maximum of about 6 or 7 inches and heights up to 75 feet.

Phyllostachys pubescens, which was introduced into the United States many years ago, is now established at several sites. It is generally adapted to the Gulf coastal plain, the Atlantic coastal plain at least as far north as Wilmington, N. C., and milder areas along the Pacific coast. As far as we know, at only three locations in the United States is this bamboo sufficiently vigorous to produce tall culms of large diameter at all comparable with those produced in Japan—Anderson, South Carolina, Bellingrath Gardens near Mobile, Alabama, and Avery Island, Louisiana. At each of these sites its growth appears to be favored by an abundant supply of soil moisture from near-by streams.

Artificially induced quadrangular bamboo is not to be confused with *Chimonobambusa quadrangularis* (Fenzi) Makino, the only species of bamboo known to produce natural quadrangular culms. This bamboo, like *Phyllostachys pubescens*, is native to mainland China but produces culms that attain a thickness of only about 1.5 inches and a height of 10 to 15 feet.

The buds of *Phyllostachys pubescens* originate from horizontal rhizomes 3 to 15 inches below the surface of the soil. By the time the young shoots have emerged from the soil in the spring, they have attained approximately the maximum diameter of the fully developed culm and the basic structure of the nodes and internodes is already well defined. Growth of the culms is a matter of elongation of the structures already formed at emergence. The soft tissues of the elongating shoot can be easily molded by a restricting form. Quadrangular culms are produced by constructing wooden frames

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Fig. 1. Wooden frames placed over young shoots of *Phyllostachys pubescens* soon after emergence, for production of quadrangular culms. The frames, tied together with rice-straw rope, are held in place by ropes extending to stakes, other frames, or near-by culms. (U.S.D.A. Photo by H. Takeda, Neg. No. 94706)

over young shoots about 1 foot tall and forcing the shoots to elongate through the restricting frames.

The frames used to mold quadrangular culms are constructed of four rough boards 6 to 10 feet long of 1 inch stock. The boards are joined lengthwise in two pairs by nails along the edges. The two halves of the frame are tied together with rope, placed over a new shoot, and supported erect by ropes tied from the top of the frame to adjacent culms or to stakes driven into the earth (Figs. 1 and 2). The young shoot, as it elongates through the chimney-like frame, is restricted in its expansion by the walls of the frame and is literally molded into a quadrangular form. When long culms are desired, a second form may be placed over the shoot soon after it emerges from the first-applied form. The usual practice, however, is to use only the single form applied soon after the shoot emerges from the soil.

Culms square in cross-section and 3 to 4.5 inches thick are produced from frames with square interior dimensions. Culms that are rectangular, oval, or triangular in cross-section are produced by employing frames constructed of boards of appropriate size. Culms rectangular in cross-section, produced by using a frame consisting of two wide and two narrow boards, range in size up to 2 to 3 inches thick and 6 to 8 inches wide. Culms with oval cross-section are produced when the frames are of a size that restricts expansion of the culm only along two opposite sides. Quadrangular culms with a jog are created when the shoot elongates through a frame of appropriate shape.

If the interior dimensions of the wooden frame are small enough to prevent the complete expansion of the culm, one of

Fig. 2. Close-up view of a wooden frame through which a culm of *Phyllostachys pubescens* has grown. The frame consists of four boards nailed together in pairs, then tied as shown. (U.S.D.A. Photo by H. Takeda, Neg. No. 94704)

Fig. 3. Bamboo culms on display in a Tokyo department store. Note especially the three quadrangular culms in the foreground. The culm on the left is approximately ¾ inches square. The middle culm, with a longitudinal groove, was produced by use of a frame too small to allow complete expansion of the culm wall. The culm on the right, approximately 2 inches thick and 6 inches wide, was formed by development through a wooden frame rectangular in cross section. The decorative mottling of many of the culms shown was created by application of wet clay containing nitric acid. (U.S.D.A. Photo by H. Takeda, Neg. No. 94712)

its walls will fold into the hollow to form a quadrangular culm with a shallow or deep trough (note the middle culm in the foreground of Fig. 3).

Skill is required to determine the correct size of the frame to be used with each young shoot to produce the desired effect. If the frame is too tight the culm may be damaged or undesirably distorted. If the frame is too loose the desired shape will not be obtained.

Edible bamboo shoots, an important agricultural product in Japan, are the principal product of many groves of *Phyllostachys pubescens*. These groves are ideal for the production of quadrangular culms, for the young shoots are larger than in most groves maintained solely for the production of culms. The largest shoots produce the largest premium-size culms. In these groves only a limited number of new culms are allowed to develop each year. An equivalent number of old culms is harvested each fall in order to keep the density relatively uniform. Only a portion of the culms that develop each spring are framed.

Most attractive designs on the surface of the culms are created by smearing or spotting the standing culms in July or

August with wet clay containing nitric acid. The acid-etched surfaces of the culms become mottled with areas of various shades of brown that stand out against the natural golden-yellow background (Fig. 3).

Most Japanese quadrangular culms are produced in the Kyoto area, one of the most important bamboo-producing regions in Japan. About 7000 quadrangular culms were produced in the Kyoto area during 1958. The farmer currently receives 400 to 500 yen, equivalent to U. S. $1.11 to $1.39, for each angular culm. For normal culms of average size he receives less than 100 yen.

The Japanese call the common form of *Phyllostachys pubescens* "mosochiku." The angular culms produced from this species are called "jinichiku," literally meaning "artificial bamboo."

Of all the distorted forms produced in Japan, the quadrangular culms are by far the most common. They are used as decorative interior exposed members in the construction of buildings and for the manufacture of decorative planters, containers, and so forth.

Japanese craftsmen fabricate quadrangular members by gluing a veneer removed from bamboo culms to solid pieces of wood that are square in cross-section. These range in size from 2 by 2 inches to 5 by 5 inches. The larger pieces closely resemble the artificially produced quadrangular culms.

The Freeze-drying of Pollens[1]

J. R. KING[2]

Introduction

The preservation of viable pollen for future study and for breeding is of considerable theoretical and practical value. The pollens of many horticultural crops will survive for many months, with decreasing viability, at temperatures just above freezing so long as the relative humidity of the storage environment is controlled and the pollen is not disturbed. Freezing to -20° C. or storage in liquid oxygen have shown promise for pollen storage, although the latter is generally impractical (Cf. Visser [15]). Pollen storage at sub-zero temperatures or a combination of low temperature and a controlled humidity are not practical, however, for long-distance shipments or the maintenance of viable pollens used in extensive plant breeding programs. The longevity of many pollens, furthermore, has not been greatly increased by sub-zero temperatures and controlled humidity.

An encouraging approach to the problem of pollen preservation is now evident in the freeze-dry method, which has been successful for fungus spores, bacteria, and blood plasma. An essential requirement for successful freezing is that the rate of temperature reduction must be rapid (2). This is not solely a function of the temperature of the freezing bath or medium, but is, rather, a function of the rapid rate of heat extraction. Meryman (9) designated two rates of freezing—"slow" and "rapid." The distinction between the two is that crystallization is wholly or predominantly extracellular until rapid rates of freezing are obtained and crystal nucleation becomes general throughout the medium.

Two methods are recognized for removing water from frozen substances *in vacuo* (13). In the first, water is absorbed by a chemical desiccant, a procedure by which the material will remain frozen until dried. In the second method, water vapor is removed by low temperature, evacuation, and condensation—a modified distillation. This method permits water to be removed readily from large quantities of materials, after which they can be sealed in their containers under vacuum.

The principle of low-temperature evaporation of water in *vacuo* followed by sublimation has been known for over 150 years, but the process now called "freeze-drying" was little more than a laboratory curiosity 25 years ago. The first use of sublimation for preserving biological substances was that developed by Shackel (11). His improvements over ordinary methods of vacuum desiccation included: (a) very rapid production of high vacua with the "Geryk" type pump; (b) freezing of the material prior to desiccation to obviate any concentration of substances and to lessen shrinkage and hardening; (c) mixing of the sulphuric acid absorbent to prevent saturation of its exposed surface with consequent lessened efficiency. The new method afforded a comparatively rapid and very accurate means for determining water in various materials, especially those which can be frozen solid. Since products of this technique are moisture-free, deterioration is reduced if precautions are taken to exclude moisture. Since Shackell's work and that of Swift (12), various investigators have contributed to the improve-

[1]Appreciation is expressed for the cooperation, advice, and interest of the VirTis Company, Gardiner, New York, relative to certain aspects of the investigations.

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ment of freeze-drying to permit application to the preservation of a variety of viable biological materials.

The freeze-drying of pollens has received limited attention. Three species and three hybrids of *Lilium* were lyophilized and stored *in vacuo* for 50 to 194 days at −20° C., 5° C., and room temperature (10). Pollen stored at the same temperatures, with a relative humidity of 35% or less showed better germination than did the lyophilized samples. The lyophilization of pollen of *Pinus palustris* Mill. (4) using filtered bull serum as a suspension agent was also unsuccessful. Since the successful freeze-drying of pollen of *Pinus taeda* (7) with this method, the investigations in our laboratory will be referred to in the following presentation of this new approach to the prolongation of pollen viability.

Freeze-drying Procedure on Pollens

Pollens of varieties of the following species have been tested with the freeze-dry method:

Agronomic Crops

Saccharum officinarum	sugarcane

Forestry Crops

Pinus taeda	loblolly pine

Ornamentals

Amaryllis spp.	amaryllis

Tree Fruits

Carya illinoensis[3]	pecan
Citrus limon[3]	Meyer lemon
Ficus carica	fig
Juglans regia[3]	English walnut
Malus domestica	apple
Prunus avium	cherry
Prunus persica	peach
Prunus salicina	plum
Pyrus communis	pear
Theobroma cacao	cacao

[3] Results are incomplete and are not included in the tables. See text for explanation.

Fig. 1. Mobile freeze-dryer. Automatically refrigerated, electric and/or gas engine powered. The tear bulbs or serum bottles containing pollen are fitted into the rubber canulas or sleeves, which, in turn, are fitted over the ports of the Bio-Dryer manifold that extends vertically above the cabinet of the freeze-dryer. (See footnote.)

Vegetable Crops

Allium cepa	onion
Ipomoea batatas	sweet potato
Lycopersicon esculentum	tomato
Solanum tuberosum	Irish potato
Zea mays var. *rugosa*[3] (hereafter referred to only as *Zea mays*)	sweet corn

The freeze-drying experiments have been carried out in a Model 10-145 Vir-Tis freeze-dryer, which is capable of handling 18 samples simultaneously.[4] The freezing bath consists of dry ice and acetone at a temperature of ca. −60° C.

[4] A mobile, automatically refrigerated, electric and/or gas engine powered freeze-dryer, specifically designed for pollen, is now available (see Fig. 1).

Vacuum varied between 50 and 250 mm. Hg.

Pretreatment of pollen has not been found necessary, although drying for one to several hours at approximately 90° F. is desirable when the pollen does not separate easily from the anthers or dehiscence is not complete. This treatment may result in a loss of pollen viability.

At first, each sample was prefrozen for 15 to 30 seconds prior to drying by sublimation, but in more recent tests we have subjected all samples to auto-freezing (see page 94).

Pollens often react specifically to changes in their artificial environment. Since too few pollens have been subjected to freeze-drying to categorize these responses, each newly-tested pollen is treated from one minte to as long as 31 hours. One-tenth to one-twelfth gram of pure pollen, or mixture of pollen and anther tissue, per each one or five ml. container is sufficient for experimental purposes, although larger quantities can be handled in larger containers. The pollen sample is inserted on the freeze-dryer port when that amount of time remains for the series run. The freeze-dryer is then shut off and the vacuum released through a nitrogen gas line inserted into one of the ports. Each nitrogen-filled tear bulb containing pollen is then torch-sealed while still inserted on its port. The more recent use of five ml. serum bottles fitted to the freeze-dryer ports by rubber canulas eliminates the need for heat-sealing. The nitrogen-filled serum bottle is easily and quickly hand-sealed with its special rubber stopper after removal from the canula. Bottles containing pollen to be stored for more than one week are inverted and immersed in melted paraffin to prevent the possible leakage of gas through the rubber. The bottles are inexpensive, easily opened, and convenient to ship, but they cannot be considered superior to tear bulbs in other respects. The sealed containers are stored for varying lengths of time at either laboratory temperature or at low temperatures.

Immediately following the opening of a freeze-dried sample, the pollen is placed in an environment for recovery to the state of germinability. The extent of, and the conditions for, recovery vary considerably among pollen of different species. To limit the number of variables which may be influencing the results, a temperature of 5° C. and a relative humidity of 60% have been used almost exclusively as the recovery environment. Limited tests have been carried out at room temperature and, for pollen of *Zea mays*, with a range of relative humidities from 3.2% to 93.9%. Since the results of the latter tests are conflicting, they have not been reported.

Viability of stored pollen should be tested both *in vitro* and by field pollinations. It is unfortunate that flowering of many species is past by the time freeze-dried samples can be tested by pollination in the current season; however, shipment of freeze-dried samples to an area of first blooming for the species will overcome this problem. Samples stored in an uncontrolled environment are opened only after the controls are dead, but should be opened every few days thereafter for several weeks.

Determinations of viability *in vitro* for most pollens have been made on sucrose-agar media with specific concentrations of sucrose for each pollen. Petri dish cultures are most satisfactory for these determinations, the pollen sown in a ring near the periphery of the dish (5). Viability of the pollens of *Ipomoea batatas*, *Solanum tuberosum*, *Lycopersicon esculentum*, and *Saccharum officinarum* has also been determined with the peroxidase reaction used as an indication of viability (8).

Results and Discussion

The selected data shown in Table I show that pollen can retain a high per-

TABLE I

EXTENSION OF POLLEN VIABILITY BY FREEZE-DRYING AND STORAGE IN NITROGEN IN AN OTHERWISE UNCONTROLLED ENVIRONMENT[a]

Pollen	*Viability at Collection* (*Germ.*)	(*Perox.*)[b]	*Days of Storage in Nitrogen at Rm T/RH*	*Longevity of Controls* (*Days*)	*Viability After Recovery from f-d State* (*Germ.*)	(*Perox.*)[b]
Pinus taeda[c]	80	—	86	18–31	79	—
	80	—	379	18–31	32	—
Saccharum officinarum	—	97	78	8–12	—	95
	—	93	140	8–12	—	89
Allium cepa[c]	20	—	191	5	20	—
	20	—	191	5	22	—
Lycopersicon esculentum	12	89	379[d]	4	8	44
	12	89	27	4	—	40
Ipomoea batatas	—	79	352	7	—	60
	—	79	354	5	—	76
Solanum tuberosum	15	40	30	4	12	28
	15	40	63	4	6	28
Ficus carica	10	—	354[d]	5	22	—
	10	—	286[d]	5	11	—
Malus domestica	23	—	56	7	23	—
	23	—	66	7	25	—
	23	—	121	7	30	—
Prunus avium	12	—	56	7	42	—
	12	—	66	7	33	—
	12	—	121	7	28	—
Prunus persica	65	—	52	6	62	—
	65	—	105	6	71	—
Prunus salicina	12	—	61	7	24	—
	12	—	66	7	17	—
	12	—	105	7	18	—
Pyrus communis	65	—	54	7	49	—
	65	—	66	7	60	—
Amaryllis spp.	15	—	33	5–10	15	—
	15	—	97	5–10	27	—

[a]Only limited, selected number of freeze-dry experimental data are included, representing results from optimum exposure of the material to freeze-dry action. Most of the freeze-dried samples stored at low temperatures and many samples in extended storage at room temperature and humidity have not been opened.

[b]Viability was tested by germination and by the peroxidase reaction(8). The latter test indicates immediately the total viability of a sample, while a germination test indicates the level of germinability and depends on proper conditions for germination, thereby not necessarily indicating total viability of a sample.

[c]Samples of *Pinus taeda* and *Allium cepa* were prefrozen; all other were auto-frozen.

[d]These samples were stored at low temperature.

centage of viability for an extended period even in an uncontrolled environment following freeze-drying and storage in an inert gas.

Evidence has accumulated (15, 6, and unpublished data) showing that low temperatures increase the viability of stored pollen. Low temperature storage of freeze-dried/nitrogen-gas-stored pollens is beneficial.

Prefreezing vs. auto-freezing. Submerging the pollen sample for 15 to 30 seconds in the freezing bath (prefreezing) prior to its insertion on the freeze-dryer port has no apparent advantage over auto-freezing, whereby the sample is inserted directly on the port and is subjected to the simultaneous actions of both freezing and drying by sublimation under high vacuum. It should be emphasized that the freezing process (whether it is prefreezing or auto-freezing) must be at the *rate* known as "slow" freezing (as defined by Meryman [9]).

Degassing of the sample. Flosdorf et al.(2) state that auto-freezing using the vacuum, may be employed without external cooling of the container. In this method it is necessary to combine the process with a preliminary "degassing" of the material by gradual and controlled evacuation.

When solutions containing protein are placed under high vacuum, they immediately froth due to the dissolved gases in the sample (1). Certain gases, carbon dioxide, nitrogen, etc., are present in the microspore. However, a comparable action in freeze-drying pollen to degassing (frothing) in lyophilized material is the "boiling" of the pollen in samples of *Zea mays*, *Carya illinoensis*, and *Juglans regia* when they are first subjected to auto-freezing. A study of degassing of various pollen samples has not yet been made.

Recovery of the microspore from the freeze-dried state. Little is known about the structural or physiological responses of the individual microspore to slow freezing and sublimation of the ice under high vacuum, the prolongation of the freeze-dry state in the microspore, or the recovery from this state to that of germinability. Wasserman and Hopkins (16) state that exposure of an organism to unfavorable environmental physical or chemical conditions may result in injury that is not immediately lethal. Subsequent treatment of such a cell, by supplying the proper nutrients or a more suitable environment, may afford the cell an opportunity to overcome the injury. Freeze-drying and rehydration, they continue, impose violent stresses on organisms. Under such conditions, non-lethal injuries may occur, as, for example, the destruction of a sensitive enzyme, the alteration of cellular permeability, or the accumulation of inhibitory substances. The conditions of rehydration and culturing become important, therefore, in determining whether the organism will survive, or whether the injury will be lethal. Van Drimmelen (14) thought that the sizes of ice crystals formed, the rate of vitrification, and the elasticity of the cell wall are only a few of the factors involved.

The recovery of the microspore from the freeze-dried state to that of germinability is a major problem. An indication of this was the nearly fourfold increase in germinability of freeze-dried samples of *Pinus taeda* pollen following an exposure of 48 hours to 5° C. and 60% relative humidity (7). The same species of pollen required 14 days in the same environment to return to the state of germinability following freeze-drying and nitrogen storage for 379 days in an otherwise uncontrolled environment (Table 1).

Wasserman and Hopkins (16) thought that the increased recovery of viable bacterial cells from the freeze-dried state should be possible if the proper rehydration medium is provided. A universal recovery medium might not be possible, however, because of differing metabolic processes. The solidified recovery medium for the microspore, moreover, is not comparable to that of the liquid media used for bacteria.

Tests on the recovery of the microspore have been based on the assumption that only water and gases are withdrawn from the cell in the freezing process, although measurements of the relation of free to bound water in the cells have not yet been made. The technique of Heckly (3), whereby moisture content is measured manometrically and the sample being tested is never exposed to the atmosphere, seems well suited to this purpose. The residual moisture content in freeze-dried material should be less than 1%. Since drying by sublimation is reported to cause few, if any, chemical changes, the recovery of the cell from the freeze-dried state would depend largely on the return of its moisture content under conditions for rehydration which may be relatively specific for each species. The dryness of the cell and the relationship between the degree of this dryness and the duration

of storage in an uncontrolled environment, considerably influence the recovery rate and, apparently, the recovery environment of each freeze-dried sample (Table I and II). Recovery will occur at room environment immediately after freeze-drying. Recovery may not be immediate in this environment following prolonged sealed storage (unpublished data on cacao pollen).

An observation which may warrant further investigation is that none of the three pollens exhibiting a high degree of degassing (*Zea mays*, *Carya illinoensis*, and *Juglans regia*) has shown recovery to the state of germinability under the conditions so far tested. The future course of investigations of the recovery problem for these pollens seems to be twofold: (1) study of factors other than the rate of rehydration in an optimum temperature either individually or together; (2) the effect of the sealed storage environment on recovery.

The nitrogen environment used thus far in the freeze-dry experiments contains approximately 2 to 3% oxygen; however, it is not known whether this amount of oxygen is the survival factor for some pollens in the storage environment but might permit a more rapid respiration rate in others which, consequently, would tend to shorten their survival in storage. An improved storage environment for all

TABLE II

THE RELATION BETWEEN DURATION OF EXPOSURE TO AUTO-FREEZING AND DEGREE OF RECOVERY, IN TERMS OF VIABILITY WITHIN A FREEZE-DRYING EXPOSURE RANGE OF A SINGLE POLLEN

Exposure to Auto-Freezing	*Viability at Collection (Percentage)*	*Days of Storage in Nitrogen at Room T/RH*	*Viability Percentage after Storage and Recovery at 5° C.—RH 60° C.*[a]
	Pinus taeda[b]		
5 min.	80	51	63
30 min.	80	86	79
1 hr.	80	54	66
3 hr.	80	54	60
4 hr.	80	51	53
7 hr.	80	54	40
	Allium cepa[b]		
1 min.	15	15	18
5 min.	15	32	19
10 min.	20	20	25
15 min.	20	53	31
30 min.	20	32	32
1 hr	20	20	20
4 hr.	17	15	17
5 hr.	20	20	18
6 hr.	20	53	13
7 hr.	20	20	17
	Ipomoea batatas		
7½ hr.	65	5	53
18 hr.	65	33	85
24 hr.	65	8	78
24 hr.	65	107	72
30 hr.	54	352	60
30 hr.	54	351	76
	Prunus avium		
5 min.	23	19	15
15 min.	23	56	26
30 min.	23	66	33
1 hr.	23	56	42

[a]Samples of *Ipomoea batatas* were tested for viability by the peroxidase reaction, the remaining samples by germination. (See footnote "b" in Table I).

[b]Samples of *Pinus taeda* and *Allium Cepa* were prefrozen, those of *Ipomoea batatas* and *Prunus avium* were auto-frozen.

freeze-dried pollens may be found by intensive studies of the effect of other gases. Storage in vacuum should also be reconsidered to improve freeze-drying techniques, although it did not give encouraging results on most stored pollens in 1958 experiments.

Germinability can frequently be inaccurately indicated in an artificial environment by the unreliability of existing viability tests. This problem is not serious with pollens which germinate well in an artificial environment (pollens of *Pinus*, of some deciduous fruits, and certain small fruits). However, many pollens germinate very poorly *in vitro*. The most widely used techniques for staining pollen grains give results which have not so far been associated with microspore viability. The development of a series of viability tests not influenced by changes in the artificial environment is certainly a problem of primary importance in pollen handling. The peroxidase reaction used in testing the freeze-dried pollens of *Ipomoea batatas*, *Saccharum officinarum*, *Solanum tuberosum*, and *Lycopersicon esculentum* is a step in that direction.

Although there is much to be learned about the morphological and physiological responses of pollens to the freeze-dry method, it seems evident that each species of pollen responds within the limits of its own range of exposures to auto-freezing. The optimum point for a particular species may be at either one exposure or it may extend over several exposures (Table III) while exposures progressively toward the minimum or maximum of the range result in correspondingly reduced viability of the freeze-dried cell. An exposure less than minimum would leave excessive residual moisture in the cell, while an exposure greater than the maximum would contribute to unsatisfactory recovery from the freeze-dried state. A relationship consequently exists between the degree of dryness in the microspore and the extent of its viability in an uncontrolled environment. The optimum degree of dryness, sealed storage environment, and proper conditions for recovery from the freeze-dried state are the major requirements for the prolongation of pollen viability in an uncontrolled environment. These experiments have only laid a foundation for necessary studies of the many problems involved.

TABLE III

APPROXIMATE LIMITS TO THE RANGES OF EXPOSURE OF CERTAIN POLLENS TO FREEZE-DRY ACTION (INCLUDING THE OPTIMUM), AS INDICATED BY THE RECOVERY OF THE MICROSPORES FOLLOWING NITROGEN STORAGE IN AN OTHERWISE UNCONTROLLED ENVIRONMENT.[a, b]

Limits to Ranges of Exposure to Auto-Freezing

1 min. to approx. 6 hrs.		*18 hrs. to approx. 30 hrs.*	
Pollen	*Optimum*	*Pollen*	*Optimum*
Saccharum officinarum	5–30 min.	*Ipomoea batatas*	24–30 hrs.
Pinus taeda	30–60 min.		
Amaryllis spp.	15–30 min.		
Ficus carica	5–30 min.		
Malus domestica	30–60 min.		
Prunus avium	30–60 min.		
Prunus persica	30 min.–3 hr.		
Prunus salicina	30–60 min.		
Pyrus communis	15 min.–1 hr.		
Solanum tuberosum	1–2 hrs.		
Allium cepa	15–30 min.		
Lycopersicon esculentum	30 min.–3 hr.		

[a] Samples of *Pinus taeda* and *Allium cepa* were prefrozen; the remaining samples were auto-frozen.

[b] The establishment of the limits of these ranges of exposure, and especially the optimum for each, should be considered subject to change by further experimentation with anticipated improved techniques.

Freeze-Dried Pollen for the Plant Breeder

The extension of breeding programs throughout the world and the increase in many areas of crops dependent on controlled pollination for production have created a growing need for the exchange of germplasm. Although only a limited number of pollens have been successfully processed by the freeze-dry method for storage in an uncontrolled environment, eventually any pollen may be so stored. This method of pollen preservation may permit inexpensive long-distance shipment of pollens. Two samples of freeze-dried pollen of *Allium cepa* stored in the laboratory for several weeks were shipped around the world in a package weighing less than two ounces. The shipment was enroute 33 days. A sample of *Pinus taeda* pollen was shipped to New Zealand and returned, and another sent to Brazil and returned. There was no apparent loss of pollen viability in any of the shipped samples. It is safe to say that certain pollens, such as those of the fruit trees, of *Allium cepa* and of *Pinus* species, may now be freeze-dried and shipped any distance in ordinary packaging.

The time is not distant when enough knowledge should be available to establish pollen distribution centers throughout the world. The distribution of pollen from selected clones can save years in the breeding of many crops. There is no present evidence that disease is carried in pollen; hence, the additional delay by quarantine restrictions on internationally-exchanged plant material may be avoided.

The need for long distance shipment of pollen is so urgent for certain breeding programs of international scope that efforts to have the freeze-dry method meet this need are already underway. The American Cocoa Research Institute, the Servicio Cooperativo Interamericano de Agricultura, the United States Overseas Mission to Ecuador, the United Fruit Company, and Louisiana State University are now cooperating on the freeze-drying of cacao polien. The success of this project will be a major step toward the eventual establishment of a worldwide pollen exchange program. Such programs can develop only from the closer and more active co-operation on the problems involved by agricultural organizations, research institutions, and individual research workers of the world.

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A Note on the Biological Activity of Root Extracts from *Pleiocarpa mutica* Benth. (Apocynaceae)[1,2]

Several organic solvent and aqueous extractives were prepared from dried roots of **Pleiocarpa mutica** *Benth. obtained from the Belgium Congo. All aqueous fractions produced a drop in blood pressure when administered to laboratory rats. A moist ethyl acetate extract produced most significant hypotensive activity. Preliminary tests indicate the presence of alkaloids in the active extracts of this species, and that the activity blocks the effect of epinephrine but is not altered by atropine. The active acetate fraction also destroyed adult and larvae stages of the nematode,* **Panagrellus redivivus** *(L.) Goody when added to test cultures.*

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Raymond-Hamet (1) reported the presence of alkaloids in root extracts of *Pleiocarpa tubicina* Stapf (Apocynaceae) and that aqueous extracts of this plant caused a drop in blood pressure of the dog. These extracts, however, produced little effect on a rise in pressure induced by epinephrine. Douglas and Kiang (2) reported the presence of alkaloids in *Pleiocarpa mutica*. Raffauf and Flagler have reviewed the alkaloids of certain genera of the family Apocynaceae (3) without extensive reference to the genus *Pleiocarpa*.

In view of the current pharmacological interest in species of the Apocynaceae and the scanty literature concerning *Pleiocarpa*, we obtained roots of *Pleiocarpa mutica* Benth. for phytochemical and pharmacological studies. *Pleiocarpa mutica* is a small tree native to the evergreen and deciduous forests of West Tropical Africa, particularly to the Belgian Congo, where it occurs as undergrowth. Taxonomically it is closely related to *P. tubicina*. This report describes the presence of alkaloids in the roots of *P. mutica* and the hypotensive and nematocidal activity observed during preliminary studies of certain extractives prepared from it.

Experimental

Dried roots[4] of *Pleiocarpa mutica* Benth. were ground to a No. 40 mesh powder in a Wiley Mill and extracted in a continuous extraction apparatus by each of a number of solvents, including petroleum ether, ether, alcohol, water, ethyl acetate, and moist ethyl acetate in an attempt to obtain pharmacologically active material for animal testing. Each extract was then concentrated under reduced pressure and the water soluble materials administered intravenously into the femoral vein of laboratory rats of the Sprague-Dawley strain. All aqueous fractions of the above extracts in doses of from 5-250 mg./kg. produced a drop in blood pressure of some degree. However, a moist ethyl acetate extract produced the most significant hypotensive activity in doses of from 5-10 mg./kg. and this extract was, therefore, subjected to further study.

One thousand grams of dried *Pleiocarpa mutica* roots (#40 powder) were extracted with moist ethyl acetate until

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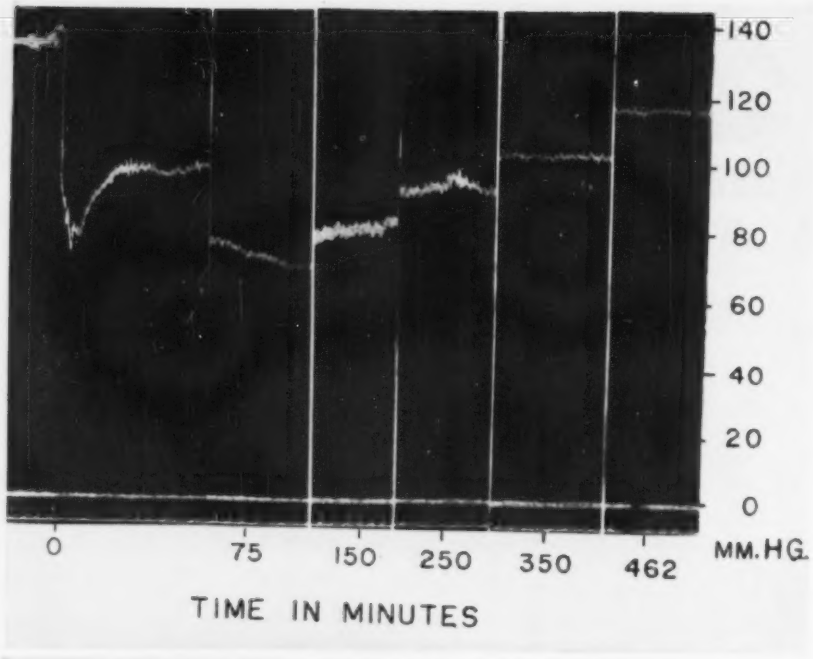
[4]Furnished by the S. B. Penick Company, 50 Church Street, New York, New York.



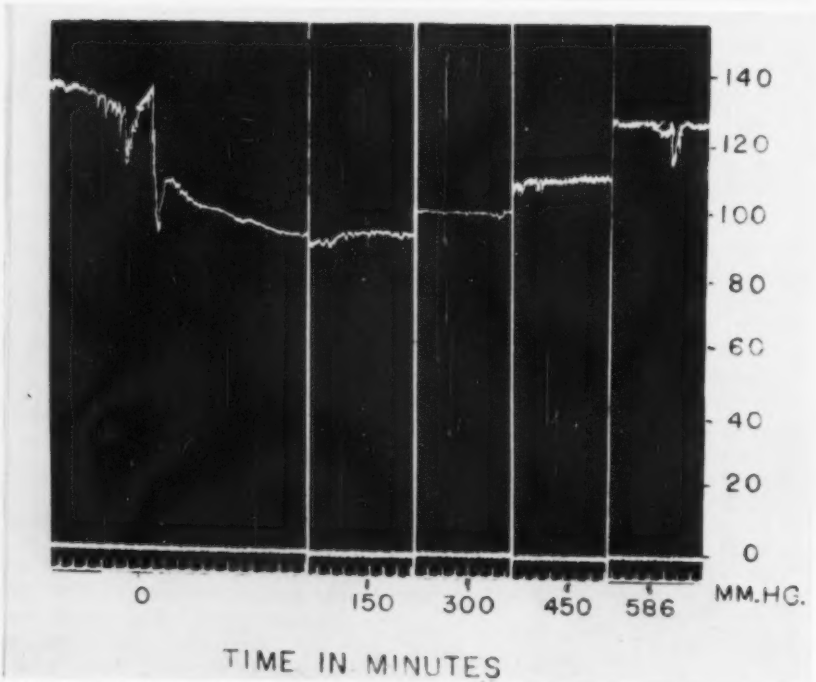


Fig. 1. The hypotensive effects of Pleiocarpa extracts (PM 239) as indicated by blood pressure recordings following intravenous injections in rats.
Upper recording, Dose 10 mg./Kg.
Lower recording, Dose 30 mg./Kg.

the drug was exhausted. The ethyl acetate solution was evaporated under reduced pressure to a resinous consistency in order to remove the solvent. The extract, free from solvent, was then dissolved in 0.5 N HCl with constant stirring. The mixture was then filtered whereupon a saturated picric acid solution was added ot the filtered acid-water fraction until no further precipitate was formed. The precipitate was collected and dissolved in a mixture of ammonia T. S. and chloroform and filtered. The chloroform solution was then washed several times with a suitable volume of a mixture of distilled water and ammonia T. S. (5:1) to remove picric acid brought over in the chloroform layer. The washed chloroform solution was evaporated to dryness. This product was designated PM 239 which represented 0.5 - 0.6% of dried *Pleiocarpa mutica* roots. It gave a positive alkaloid test with Mayer's and Dragendorf reagents and picric acid test solution. It also gave a marked fluorescence in the ultraviolet region of the spectrum. Further studies of the chemical nature of components of this extract are in process and thus far two as yet unidentified crystalline components have been isolated.

Hypotensive Activity of the Ethyl Acetate Extract. Rats of the Sprague-Dawley strain weighing 150-225 g. were selected for blood pressure studies. Animals of both sexes were given water *ad lib.* but were fasted from eighteen to twenty-four hours prior to use. The rats were anesthetized by an intraperitoneal injection of 1.0 g./kg. of urethane. The normal blood pressure of urethane-anesthetized animals was from 80 to 120 mm. Hg. The effects of the *Pleiocarpa* root extracts on blood pressure were recorded by direct cannulation of the carotid artery with a system consisting of a mercury manometer connected to the cannula by a fluid bridge of 7.5% sodium citrate solution. The effect on the blood pressure was recorded on a slowly moving smoked kymograph. Heparin sodium, 0.01 mg./kg. was injected intravenously, and an equal amount added to the cannula to prevent clotting. The moist ethyl acetate extracts of *Pleiocarpa* (PM 239) were dissolved in acid water (acidified by HCl) at a pH of about 5.5 to 6.0 and administered via the femoral vein. The indices of activity used to compare different fractions possessing a hypotensive effect were as follows: (a) the maximum percentage drop of the blood pressure, and (b) the duration of the hypotensive effect. *Pleiocarpa* extract (PM 239) at the dose level of 5 and 10 mg./kg. produced a drop in blood pressure of from 43 ± 6% to 50 ± 5% with the duration of 335 ± 29 to 620 ± 64 minutes respectively (Fig. 1). The LD_{50} in mice by intraperitoneal administration of this extract was 130 mg./kg. (Table 1).

Studies were then made of the effects produced by this extract on animals with elevated pressor rise induced by epinephrine (0.1 ml. of 1:1000 and 1:100,000 solutions). Results shown in Fig. 2 indicate that *Pleiocarpa* extract in doses of 5-10 mg./kg. reversed the pressor rise produced by epinephrine. On the other hand, as shown in Fig. 2, the activity of this extract was not blocked by atropine in rats previously atropinized by intravenous doses of 1 mg./kg. atropine sulfate.

TABLE I.

THE LD_{50}* OF *Pleiocarpa* ETHYL ACETATE EXTRACT (PM 239) IN MICE BY INTRAPERITONEAL ADMINISTRATION

Sample No.	*Dose (mg./Kg.)*	*Mortality Female*	*Male*	*Total Mortality*
PM 239-3	50	0/4	1/6	1/10
	100	2/4	2/6	4/10
	150	2/4	3/6	5/10
	200	3/4	5/6	8/10
	250	3/4	5/6	8/10

*LD_{50} (calculated by Litchfield and Wilcoxon Method) 130 mg./Kg.

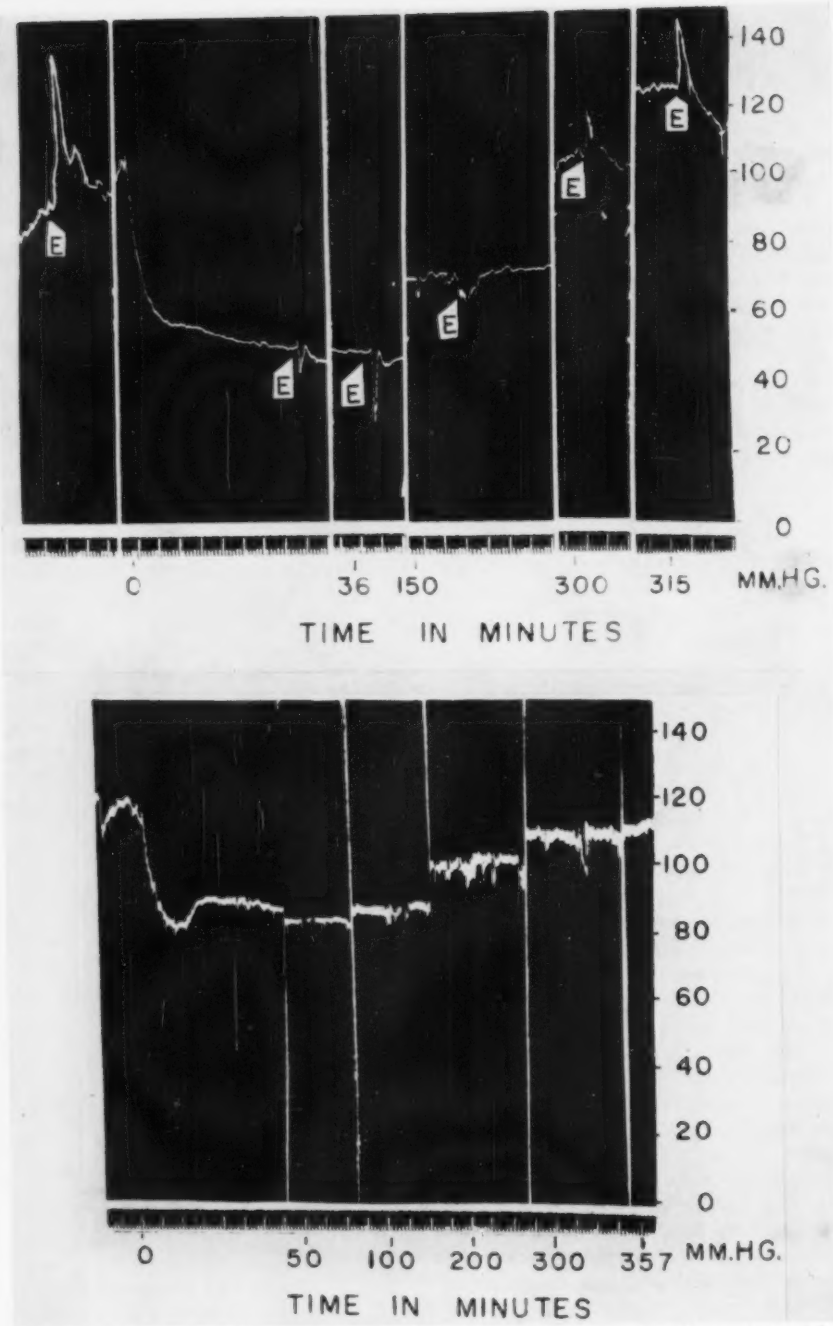


Fig. 2. Effects of Pleiocarpa extract (PM 239) intravenously on epinephrine and atropinized rats.

Upper recording: E, Epinephrine (1:100,000) dose 0.1 ml: Pleiocarpa extract, dose 10 mg./Kg.

Lower recording: Rats previously atropinized 1 by 1 mg./Kg. atropine sulfate: Pleiocarpa extract dose, 10 mg./Kg.

Nematocidal Properties[5]. *Pleiocarpa* extract (PM 239) was also tested for nematocidal activity using *Panagrellus redivivus* (L.) Goody 1945, the sour-paste nematode, as the test organism. Active adults and larvae were recovered from two-week old oatmeal cultures and placed in tap water. One drop of nematode suspension was added to four drops of the extract (7 mg./ml.) in Beltsville watch glasses. This gave a concentration of 5.6 mg./ml. Control dishes contained nematodes in tap water only. The first observation after four hours revealed that all the original worms were dead. Four newly born larvae remained alive. At the 24-hour reading, two newly hatched larvae were found alive in each of two dishes. No life was, however, present at the 48 hour reading (see Table II). PM 239 extract appeared to cause complete disorganization of organs and protoplasm of the worms. Fat globules appeared to be broken down and distributed throughout the body of the worm. The killed nematodes took on a yellowish-brown discoloration and organs could not be distinguished.

TABLE II

NEMATOCIDAL ACTIVITY OF *Pleiocarpa* EXTRACT IN TEST ORGANISM, *Panagrellus redivivus* (L.) GOODY

Sample No.	*Percent of Living Adult Nematodes after Treatment**		
	4 hrs.	*24 hrs.*	*48 hrs.*
PM 239	0.0	0.0	0.0
Controls	97.4	90.0	68.0

* Av. of 3 dishes/treatment; Dose 7 mg./ml. *Pleiocarpa* extract.

[5]The authors are indebted to Professor George J. Stessel of the College of Agriculture, University of Rhode Island, for the preliminary nematocidal study.

Summary

Evidence is presented that roots of *Pleiocarpa mutica* Benth. possess components in an ethyl acetate extract with hypotensive activity when administered intravenously to laboratory rats. Preliminary studies indicate that this activity might be sympatholytic since it was found to block the effect of epinephrine. The effect was, however, not blocked by atropine.

The nematocidal activity produced by roots extracts of the same plant indicate a protoplasmic poisoning effect of rather broad intensity. It is interesting to note that both adult and larvae stages of the worm were destroyed by components of the extract.

The conventional alkaloid tests (Mayer's, Dragendorf and picric acid test solutions) indicate the presence of alkaloids in the pharmacologically active extracts of *Pleiocarpa mutica* roots. Studies are being continued to further elucidate the character of these components.

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Extractive Studies of the Roots of *Pteryxia terebinthina var. terebinthina* and the Isolation of Pteryxin

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The discovery of coumarin and chromone derivatives in several umbelliferous genera and species studied by Späth (1), and the continued clinical interest in the chromone khellin from *Ammi visnaga* (L.) Lam., led to our examination of some American *Umbelliferae* for the possible presence of similar substances. During exploratory studies of a number of species of *Umbelliferae*, the evaporation of a petroleum ether extract of the roots of *Pteryxia terebinthina* (Hook.) Coult. & Rose var. *terebinthina* yielded a considerable quantity of prismatic crystals.

Materials, Methods, and Results

Several lots of the roots used in this study were obtained in Sherman County, Oregon. Their identity was ascertained from herbarium specimens submitted to Dr. Lincoln Constance of the University of California at Berkeley, California. (Additional voucher herbarium specimens have since been deposited in the herbarium at the University of Minnesota in Minneapolis.)

The roots were broken into pieces and air-dried until less than ½ of 1% of their weight was lost in twenty-four hours. When milled to a #20 mesh fineness, most lots were found to contain six to seven % of moisture.

Separate Extractions. Separate extractions of 15 gm. samples were conducted, each for a period of eight hours, in a Soxhlet extraction apparatus. Twenty-two different solvents were used in this series. Extractions with water were incomplete because of the formation of a gelatinous mass in the extraction capsule. The result of this series of extractions is presented in order of increasing extract yields in Table I.

The colors of the several extracts after drying ranged from light amber to a very dark reddish-brown. Based on the Mun-

TABLE I

EXTRACTIVE YIELDS FROM SEPARATE SOXHLET EXTRACTIONS
(Arranged in order of increasing yields from 15 gm. samples)

Extraction Solvent	*Per Cent Extracted*
Petroleum ether (B.P. 20°–40° C.)	11.82
Isopropyl ether	12.57
Carbon disulfide	12.95
Petroleum ether (B.P. 34.5°–55° C.)	13.13
Cyclohexane	13.32
Toluene	13.41
Benzene	13.73
Ethyl oxide U.S.P.	13.79
Carbon tetrachloride	13.83
Petroleum ether (B.P. 60°–90° C.)	13.87
Petroleum ether (B.P. 90°–120° C.)	13.88
Chloroform U.S.P.	14.22
Ethyl Acetate	14.61
Xylene	14.81
Isopropyl alcohol	16.31
Acetone	17.62
N-butyl alcohol	21.33
Isoamyl alcohol	23.70
Ethyl alcohol 95% U.S.P.	31.75
Methyl alcohol 99%	31.89
Pyridine	34.48
Glacial acetic acid U.S.P.	53.64

[1]Abtracted from Ph.D. thesis submitted to the University of Minnesota by Tracey G. Call. The authors wish to thank Dr. T. O. Soine for his valuable advice in certain aspects of this study.

[2]Fellow of the American Foundation for Pharmaceutical Education, 1951-52; World Life Research Institute, Reche Canyon, Colton, California.

[3] Professor of Pharmacognosy, University of Minnesota.

Submitted for publication 28 December, 1959.

sell color notation system, most of them were of a 2.5 YR hue with a 4/6 to 2/4 value/chroma.

Prismatic crystalline material appeared in the petroleum ether and in the cyclohexane extracts upon evaporation of the solvents. Crystal formation in most of the other extracts required several months to a year or more.

Successive extractions. A representative 15 gm. sample of powdered root was extracted successively with petroleum ether (B.P. 20°-40° C.), acetone, ethyl alcohol, glacial acetic acid, and water. Following each extraction, the solvent was allowed to evaporate completely from the marc before extraction with the next solvent. The yields obtained in these extractions are listed in Table II. All extracts exhibited a greenish fluorescence when examined under ultraviolet light. Large prismatic crystals were formed only in the first (petroleum ether) extract. Sucrose crystallized from the alcoholic extract and was identified on the bases of melting point and the nature and rate of formation of the osazones of its hydrolytic products. Several other successive extraction series were performed with various modifications, but none yielded additional crystalline materials.

Purification of Crystalline Material. The unidentified crystalline material, for which the name pteryxin is proposed, was difficult to purify inasmuch as resinification or a similar change often occurred whenever recrystallization was attempted. Attempts were made to purify the compound by the procedure used by Späth (2) in purifying several coumarin derivatives. This method utilized potassium hydroxide to open the pyrone ring which in turn was reclosed by reaction with an acid. The method had been unsuccessful with some coumarin derivatives and was likewise found unsuccessful in this study with pteryxin. The entire study of pteryxin was hampered by the difficulty encountered in preparing highly purified samples.

TABLE II

EXTRACTIVE YIELDS FROM SUCCESSIVE EXTRACTIONS OF A REPRESENTATIVE SAMPLE

Extraction Solvent	*Per cent Extracted*
Petroleum ether (B.P. 20°–40° C.)	11.20
Acetone	2.45
Ethyl alcohol 95% U.S.P.	16.78
Glacial acetic acid	17.42
Distilled water	7.28
Distilled water, additional 12 hours	5.43

Unidirectional paper chromatographic examinations indicate that pteryxin is easily degraded during chromatographic development. Under conditions of chromatography with non-polar solvents which do not permit hydrolysis, it appears to be a homogeneous compound.

Physical Properties of Pteryxin. The highest melting point of pteryxin attained in this study was 81° C. (uncorr.). Pteryxin could not be sublimed but could be distilled at 195° C. at a pressure of less than 1 mm. of mercury, without apparent change, forming a glassy solid. The solubility of pteryxin at 25° C. in petroleum ether (B.P. 20°-40° C.) was 4.2 mg./ml.; in petroleum ether (B.P. 90°-120° C.) 19.4 mg./ml.; and in 95% alcohol, 209.6 mg./ml. It was found to be very soluble in carbon disulfide, benzene, ethyl oxide, chloroform, and acetone. Its solubility in water at 20° C. was 0.025 mg./ml. The density of the crystals determined by a buoyancy method in potassium iodide solution was found to be 1.22. The U-V spectrum of freshly made solutions of pteryxin in alcohol was very similar to that reported for visnagan (3), a compound which Cavallito and Rockwell were unable to obtain in crystalline form.

Chemical Properties of Pteryxin. Basic solutions of pteryxin are yellow and are strongly fluorescent, exhibiting a greenish color under ultraviolet light. Tests for nitrogen, sulfur, and halogen by

the methods of Shriner and Fuson (4) yielded negative results. No methoxyl group was present.[4] Lack of color change with ferric chloride solution indicated the absence of phenolic hydroxyls.

Analytical Data:

Calculated for $C_{22}H_{24}O_7$:[5] C, 65.99; H, 6.04.

Found: (ave. of three) C, 65.97; H, 6.08.[4]

Saponif. Equiv.: Calcd. for $C_{22}H_{24}O_7$: 133.47.

Found: 140.2.

Mol. Wt. (Rast): Calcd. for $C_{22}H_{24}O_7$: 400.41.

Found: 370 to 425.

The physical and chemical properties of pteryxin indicate that it is probably a coumarin or chromone compound.

Pharmacological Activity. The powdered roots, when fed to mice, increased the blood coagulation time significantly (5). Pteryxin was found to be a spasmolytic to spontaneously contracting rat uteri *in vitro*. Under the conditions of this study, it possessed approximately twice the spasmolytic potency of khellin and four times the spasmolytic potency of papaverine hydrochloride (5).

[4]Clark Laboratories, Urbana, Illinois, and University of Minnesota Microanalytical Laboratory.

[5]Dr. T. O. Soine of the University of Minnesota has since reported that, while similar analytical data were obtained also by Willette and Soine, structural investigations indicate the formula is more likely $C_{21}H_{20}O_7$. (Personal communication.)

Summary

Soxhlet extractions of *Pteryxia* roots yielded a prismatic crystalline material for which we have proposed the name pteryxin. Powered *Pteryxia* root causes a significant increase in the blood coagulation time of mice. Pteryxin is a spasmolytic to isolated rat uteri.

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BOOK REVIEWS

Fruits for Southern Florida. David Sturrock. 186 pp. illus. Southeastern Printing Co., Inc., Stuart, Fla., 1959. $4.00.

Here is a general treatise that covers every aspect of the growing and use of fruits in southern Florida. The author is acquainted with his subject both from the practical side of farming and horticulture and from the technical side of nomenclature, nutrition, ecology, and pathology. The current volume is an amplification and revision of Sturrock's *Tropical Fruits for Southern Florida and Cuba and their Uses* (1940).

Following a brief resume of the history of introduction of fruits into Florida, the opening chapters deal with the soils and climate of southern Florida. The detailed discussion of climate points up the occasional cold weather that is the limiting factor in the growth of some kinds of tropical fruits. Fine maps on which are recorded the mean temperatures and rainfall for a number of stations can be used in conjunction with the land map (p. 28) as a basis for deciding which species of fruit plants may be successful at any point in southern Florida.

The chapter on cultural notes deals with general aspects of the light soils of Florida and the many ways of dealing with the nutrient deficiencies that may develop in these soils. Practices here vary markedly from those familiar to gardeners who have previously lived in the heavy-soil areas of temperate North America. Pruning is taken up in general terms, but as Sturrock notes, "There are no set rules for pruning." The author fails to note that the pruning of tropical plants can be a matter of personal preference and, unlike the situation with regard to many temperate zone plants, the gardener can experiment with various procedures and can be confident that a few months growth in the tropics will probably erase any serious errors that he may have made.

Sturrock's chapter on plant disorders is weak. To discuss plant diseases in general terms is admittedly difficult, but this section would have been improved by a fuller discussion including a separation of fungus diseases into categories (molds, yeasts, etc.) with specific notes on symptoms and treatment. Here again, the growth rate of tropical plants is so much faster than that of temperate zone plants that diseases are frequently of less consequence. With a good cultural program, the growth of the plant may outdistance the spread of an infection.

The chapters on home-yard plantings and uses of the fruits are of more interest to the general reader than are many of the other chapters. If home landscaping can be made both useful and ornamental, its value has been more than doubled. The body of the text on specific fruits is arranged by plant families in alphabetical order. A general statement places the family in perspective and notes the relatives of the fruits to be discussed. Each fruit in the family is then treated in detail. A description of the plant and fruit is accompanied by notes on culture, pathogens, uses and, when available, an analysis of the nutritive value of the fruit. In cases where numerous varietal selections are available, the varieties are discussed. The text is full and will provide ample information both for homeowners who are looking for new fruits and for gardeners who are experienced with the plants under discussion. The text is followed by a selected bibliography and a complete index.

Only two major deficiencies are apparent, and they do not detract from the value of the book. The first is the plates that illustrate the text. The frontispiece is a very commendable color photograph. The other illustrations are line drawings, which fail

to achieve the seemingly intended artiness. Furthermore, they are not reasonable representations of the plants that they purport to illustrate. Details are either lacking or are very inaccurately drawn. Sections of fruit are not labelled as such, and their significance is apparent only to someone who already knows what the section of the fruit looks like. The second deficiency is in the editing of the text. Several grammatical slips and considerable poor syntax are obvious. This in no way diminishes the value of the information imparted but merely makes it less palatable.

Fruits for Southern Florida is highly recommended to everyone with an interest in tropical fruits. It will prove particularly valuable for anyone who is gardening in southern Florida.

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Using Wayside Plants. Nelson Coon. 254 pp. illus. Hearthside Press Inc., New York, 1960. $3.95.

In these days when more people are traveling for greater distances and having more leisure hours in which to do it, it is refreshing to come across a volume regarding common plants and their uses that is written for the average person. Percentagewise, the segment of our population that will use this book is undoubtedly small, but it is hoped that through publication of the book greater interest in the natural world around us will be stimulated. Because the author encourages the collecting of certain plants or parts thereof, some conservationists are apt to be alarmed; but Mr. Coon wisely distinguishes true conservation from the philosophy of non-use, and further reduces concern by arbitrarily selecting for discussion 100 plants that are generally common and are apt to be found accessible to most of the millions who reside in the populous northeastern section of the United States. Furthermore (and this is important) the author has selected plants with which the average person is likely to be familiar already, and concerning which he desires to learn more.

Mr. Coon's list of recipes for using wild plants as food is a large one, and cook-book accuracy is used in itemizing the ingredients. Many of these recipes will tempt the reader, or at least make him wish that he only had the time to try them out. Concerning the chapters on native dyes and native medicines, it is fortunate that their importance for the twentieth century is not overstressed, as it so often is. Mr. Coon recognizes that native dyes have been replaced in large part by coal-tar derivatives, and his discussion of medicines should be quoted verbatim:

"It should be understood in this discussion that the author is not making any effort to build up a case for the 'herbalist' . . . the all-inclusive statement of the modern herbalist that 'medicines made exclusively from plants are the natural cure for human disease and ill health' is a sweeping one."

On the subject of dyes, another of the author's quotations is interesting:

"This chapter is made a part of this book not with any feeling that our readers will want to go out and buy raw wool, dye it, and spin and weave their own clothes nor perhaps may ever do any dyeing, but because no survey of plant values can ever ignore this fundamental usefulness of wild plants."

The itemizing of native dye plants and the colors they produce, together with proper instructions for collection and mordanting, make interesting reading even when not put into actual use by the reader. The same principle applies in reading about the medicinal properties of wild cherry bark and boneset tea, or the formula for making a hand lotion with Irish moss. The chapter on the use of native plants for decoration and landscaping is a welcome one. Too frequently we struggle to obtain some exotic where a native would do as well. The paragraphs on plant fragances and bouquet arrangements make delightful reading. The chapter on poisonous plants is a practical one.

Too often the average person's contact with plants has been in some botany course where tedious and technical terminology was stressed. A book such as *Using Wayside Plants* is welcome because of its simplicity. A word of criticism is in order for the geographic-distribution maps that accom-

pany many of the plant descriptions. Although geographical coverage of New England and nearby states is adequate, the Midwest and the South have literally been left out in a number of instances where these regions should have been included. Incomplete mapping is shown for such plants as hawthorn, poplar, basswood, sassafras, bearberry, New Jersey tea, winterberry, witch hazel, smooth sumac, boneset, strawberry, wintergreen, pickerel weed, skunk cabbage, and bloodroot. However, these comissions do not detract from the over-all functional usefulness of the book. Illustrations of the plants are made with a view toward easy identification—extra frills are left out—and the type of drawings, which are satisfactory for the purpose, enables the book to be placed within an inexpensive price range.

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Annual Review of Plant Physiology. Vol. II. L. Machlis and W. R. Briggs, Editors Annual Reviews, Inc., Palo Alto, California, vii-468 pp. 1960. $7.50.

Starting with the current volume, the Annual Review of Plant Physiology contains a cumulative index to its articles. The outline is essentially a review of the manifold sub-fields included in this discipline. A logical consequence of this action is to have the headings of the outline in the table of contents. For convenience, 12 heads have been used which bracket all fields of plant physiology.

Examination of these headings and the specific topics under these headings, confirms the idea long held by this reviewer that there is no utility or *raison d'etre* for advanced textbooks in plant physiology. Even the superior undergraduate student can obtain a plethora of data from the reviews and, more important, he will get a glimpse of the scope of plant physiology which no text could provide. The admirable policy of re-scheduling reviews in the more rapidly advancing fields insures an up-to-date treatment of any given topic.

One cannot over-estimate the frequency with which the research worker, teacher, and graduate student will turn to the volumes of this distinguished set of annual reviews. The efforts of the editors to maintain a high level of synthesis and integration within and among articles have paid off handsomely. The Annual Review of Plant Physiology has a sweep and unity not usually achieved by other periodicals of similar purpose.

The volume under consideration is as good as its predecessors, that is to say, it is generally excellent. The individual authors are all well-known experts in their fields, the topics are timely, and the selection is catholic.

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Some Fruits and Nuts for the Tropics. William C. Kennard and Haro'd F. Winters, 135 pp. 95 figures. Agricultural Research Service, United States Department of Agriculture, Misc. Publ. 801. 1960. Obtainable from Superintendent of Documents, Washington 25, D. C. for fifty cents.

The Federal Experiment Station in Puerto Rico, at Mayaguez, often has encouraged publications by its staff on tropical plants useful for one reason or another. *Some Fruits and Nuts for the Tropics* is a worthy and worthwhile addition to that series of publications.

The plants covered by this work are ones that have been grown, observed, and evaluated at Mayaguez by the two authors, who are horticulturists with long experience in the tropics. The publication is divided essentially into two important parts. The first part covers variations in climate and soils, sources for and methods of propagation of plants, and the culture of these plants. The second and greater part is taken up with an account of the various plants selected for discussion. Each discussion gives the scientific name, synonyms if there be any, common name or names in both English and Spanish, and the family to which the plant belongs. This is followed by a description of the plant and by a discussion that includes useful and interesting information about the fruit or nut, references to varieties, and literature citations. Methods of propagation and culture are mentioned briefly.

Each plant described is also illustrated. Following the descriptive text are a bibliography, a list of plants by families, and an index to common and scientific names. This publication should be most useful to those who are horticulturally inclined and who are fortunate enough to live where fruits and nuts for the tropics may be grown.

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Grass Productivity. Andre Voisin. 353 pp. illus. Philosophical Library Inc., New York, 1959. $15.00.

The author, a member of the Academy of Agriculture of France, is an observing farmer and also is in charge of the National Veterinary College of Alford (Paris). He possesses a remarkable combination of scientific knowledge, practical experience, and liaison with grassland authorities. In recognition of this, he was selected to preside at one of the sessions of the 8th International Grassland Congress which met in England in July, 1960.

This book, which was translated from the French by Catherine T. M. Herriot, is in twelve parts, each with well-illustrated chapters, and contains 149 references. It was written by a man who carries on his own scientific studies, his main concern being "the relationship of the soil to the animal and man through grass." Mr. Voisin considers the grass, the cow, and the requirements of each and then proceeds to show that "rational" grazing can provide the means for efficient production from pastured grasslands. Recognizing that "too often farmers accept pasture for what it is and not for what it could be if they put into its management the same level of technical knowledge as they apply to their tillage crops," the author presents evidence for a "rational" grazing system that will maximize production.

In addition to information from research centers and farms in America, Germany, France, New Zealand, and Great Britain, the book provides a vast fund of practical information and guidance given by the author from his own experience with rational grazing over a 13-year period on his own farm. He explains in detail the features of this system of grazing management, which he has used so successfully. He describes this alternate grazing system very clearly with facts and figures that can be adjusted to meet the needs of any farm, and outlines the details of (1) the pattern of pasture use and of rest, (2) number and layout of paddocks, (3) fertilizer application, (4) rate of stocking, etc.

The importance placed upon grazing management may be questioned by some, because the production of any grassland is dependent upon so many factors. Choice of crop, choice of site, fertilization, and other factors may be equally important. The author has done a superb job in pointing out the benefits that can come from improved grazing management when other factors are favorable. He has entitled the book "Grass Productivity" and has devoted most of the book to "rational" grazing, which to him provides the means of getting high production. A descriptive subtitle would be an improvement.

This is a valuable reference book that should find a place in agricultural libraries and with those engaged in pasture research and teaching.

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Soil, Grass and Cancer. Andre Voisin. 302 pp. illus. Philosophical Library Inc., New York, 1959. $15.00.

This book carries the subtitle "Health of Animals and Men is Linked to the Mineral Balance of the Soil." It follows as a sequel to the author's *Grass Productivity*, also published in 1959.

The author, a member of the Academy of Agriculture of France, is a farmer and is in charge of the National Veterinary College of Alford (Paris). The book was translated from the French by Catherine T. M. Herriot and Dr. Henry Kennedy, who is secretary of the Irish Agricultural Organization Society Ltd. There are 66 short chapters and over 400 well-cited references in the book.

The author attempts to establish first of all, with various examples, the methods by which soil minerals condition the organic matter and govern the metabolism of the

vegetable cell. He believes that the influence of the soil is transmitted to cells of the animal and that the metabolism of cells of human tissues is secondarily affected by the same influence. He emphasizes that when certain soil elements are modified, disappear, or are exaggerated, cellular metabolism becomes disordered, and illness results. The roles of the different inorganic elements in nutrition are shown through the illnesses that result from deficiencies and imbalances in these elements. He relates the observations and studies that were made in 13 years of a "rational" grazing system used on his farm in northern France, and concludes that deficient soil and deficient grass cause the degeneration of cell functions which we call cancer. The last chapters of the book (33 to 39) deal with cancer and the conditions under which it appears; earlier chapters deal with the less serious illnesses, as well as cancer, that result from malfunctioning cells. Mr. Voisin visualizes that shortages of trace elements and of the enzymes these elements support cause irregularities in cell growth and metabolism, resulting in cancer and other illnesses.

The evidence on which Mr. Voisin bases his conclusions is striking and well presented. Much of it may be disputed and widely discussed and may contradict conventional beliefs in some respects. He succeeds in making the reader aware of the implications of some of the modern agricultural practices as they relate to public health. His ideas will be extremely thought-provoking to observing farmers, agricultural scientists, veterinarians, dieticians, and physicians. These readers will appreciate the able support of the projected thinking that he has developed from studying extensive scientific literature and from results of his own investigations.

The author emphasizes the need for paying more attention to building up health through nutrition that starts with balanced fertility in the soil. He hopes that informed people will be able to gain from his book some knowledge of the problems of medical biology and of the possibilities, through protective medicine, of removing some of the causes of ill health, disease, and, in particular, cancer. The book should be a valuable addition to agricultural libraries and should be made available to those interested in the functioning of living cells.

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Decorative Trees and Shrubs. Plates by Hans Schwarzenbach; text by Hans Zaugg and Hans Coaz, translated and adapted by Herbert L. Edin. The Viking Press, New York, 1960. $20.00.

Decorative Trees and Shrubs contains 60 seven-color plates (12¼" x 9⅜") of ornamental plants. The plants illustrated were chosen purely on the basis of their decorative value for landscaping. The choice is a most admirable one. Some of these ornamentals, e.g., *Aralia spinosa, Chaenomeles lagenaria, Cornus florida, Diervilla florida, Forsythia suspensa, Ginkgo biloba, Hibiscus syriacus, Larix decidua, Picea abies, Rhus typhina, Rosa rugosa,* and *Symphoricarpos albus,* are well-known in cultivation; others, e.g., *Callicarpa bodinieri* var. *giraldi, Corylopsis spicata, Fothergilla gardeni, Hamamelis japonica, Picea abies pendula,* and *Staphylea colchica,* deserve to be better known than they are.

The habit illustrations, printed in Switzerland by lithographic color superposed on line drawings, are intended to show "what the appreciative eye really sees, rather than what an unthinking camera would record." This purpose is well achieved, although the color reproduction is not always faithful to life. Accompanying many of the habit illustrations are detailed drawings, not in color, of leaves, flowering branches, fruits, cones, etc. Facing each plate is a commentary—adapted obviously for a British audience—that gives brief notes on homeland, height, situation, flowers, decorative value, etc. for each of the plants. Indices to common and scientific names bring the book to a close.

The assertion in the introduction that all these trees and shrubs are hardy over most of North America will not, I hope, dupe gardeners in Bemidji, Minnesota or Moose Jaw, Saskatchewan into planning to feature *Taxodium distichum, Calycanthus floridus, Cladrastis lutea, Cotoneaster salicifolia, Laburnum watereri,* or *Rhododendron luteum*—among others—in their landscaping. In these cities, which have nearly half of North

America *north* of them, as well as in other localities in hardiness-zone 1, only about seven of the sixty species discussed in the book might possibly be grown successfully. In reality, many of the species are hardy only from zone 3 southward, and even in this zone some of them are unreliable.

Neither the paper nor the binding of the book are of the quality that the purchaser might expect to receive for $20.00.

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"De China"

In Colonial times in Mexico and Central America there was very little fine quality merchandise manufactured locally. Products of the mines, of the forest and of agriculture were sent to Spain or other European countries and in return, those things desired in the colonies were brought in from Spain or elsewhere. There were, as there still are, differences in quality of goods but it was often thought that the best quality merchandise came from the Spanish province of Castilla.

In the days of the galleons much fine merchandise found its way into Mexico and then to Central America from China by way of Manila and the long and tedious galleon trip across the Pacific to Acapulco in Mexico. The best of the hand made *mantillas*, among other things, came in on the galleons. These were made in China but came to America by way of Manila. They became known as *mantillas de China* or *mantillas de Manila*, indicating their place or supposed place of origin. It was not long before the words *"de China," "de Manila,"* or *"de Castilla"* came to be applied to any superior object, indicating that it was good or useful rather than indicating its place of origin.

There are many names of useful plants in Mexico and Central America to which the words *de China* or *de Castilla* have been attached. These names have nothing to do with the geographical origin of the plants. *Aguacates de China* (*Persea americana* Mill.) is often used in Mexico for fine fruits of the strictly American avocado. Ordinary avocados are distinguished as *aguacates corrientes*, or simply as *aguacates*. *Caña de Castilla* is often the name given to the grass *Gynerium sagittatum* (Aubl.) Beauv. in Central America. The canes of this plant were found to be most useful in house construction, fence building, basket making, and a score more of things. The plant then acquired the name *caña de Castilla*, not because it originated in Castilla, but because it was useful or good.

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